PLANNING FOR THE FEASIBILITY
OF RURAL PUBLIC TRANSIT

By

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PREFACE

The purpose of this research was to develop tools useful in planning for the feasibility of rural public transit. The specific areas reviewed included estimation of ridership, routing, budgeting and performance monitoring. The study used data supplied primarily by Section 18 transit operators in Oklahoma, and the Oklahoma Department of Transportation. A technical assistance grant with the Oklahoma Department of Transportation provided partial funding of the research.

Trying to thank everyone who assisted me in this work is an impossibility, because friendships provide support in subtle ways. But I must try to extend my gratitude to a number of people.

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CHAPTER I

INTRODUCTION

There is an increasing awareness of the importance of transportation to the economic health and quality of life in an area. It is necessary not only for daily commutes to work, but also for shopping, medical care, and social services. Often those affected most by inadequate transportation are the elderly, poor, and handicapped.

People in rural America have relied heavily on private automobiles due to the lack of public transportation services. A need arises because rural areas are often characterized by low income and elderly populations. These people may have critical needs which are provided by public services located in population centers. But transportation to those centers is a prerequisite. The fact that the lack of adequate transportation prevents many people from fully utilizing resources available to them has led some to regard transportation as a crucial resource in improving the quality of life in rural areas (Burkhardt, 1981).

Many problems exist for the provision of rural public transit. Low population densities and long distances between clients make the traditional fixed route provision of transportation difficult. In addition, automobiles have long been used as the primary transportation mode, and the habit of using public transit may be difficult to establish. Even those that lack automobiles may prefer to wait until a relative or friend can drive them to their destinations because the private automobile is perceived as more convenient.

Despite these obstacles, the recognition of the need for public transit in rural areas has persisted. In response, federal programs have gradually considered rural programs along with urban transit. In 1967, the former Office of Economic Opportunity started programs in non-metropolitan areas to help people out of their poverty cycles. Transportation was identified as a need, and the Community Action Programs provided services to segments of the low income population. In addition, the Administration on Aging was authorized to provide transportation under Title III of the Older Americans Act (Saltzmann and Newlin, 1981).

In 1973, Section 147 of the Federal-Aid Highway Act, known as the Rural Highway Public Transportation Demonstration Program, was passed. However, it was not until 1976 that the first Section 147 projects began (Burkhardt, 1981).

In 1978, the Urban Mass Transportation Act of 1964 was amended by adding the Section 18 Formula Grant Program for Areas Other than Urbanized. The objectives of the Section 18 program as stated in the legislation are:

> To improve, initiate, or continue public transportation service in nonurbanized areas by providing financial assistance for the acquisition, construction, and improvement of facilities and equipment and the payment of operating expenses by operating contract, lease, or otherwise.

The assistance is provided through formula grants, and projects must provide for maximum coordination of public transportation sources and maximum feasible participation of private operators. Another important amendment to the Urban Mass Transportation Act introduced the Section 16(b)(2) program, which provides funding for transit vehicles to meet the needs of elderly and handicapped.

Oklahoma Setting

An examination of the 1980 Census for Oklahoma confirms much of the scenario presented for rural public transit needs. Urban and rural comparisons are made to highlight differences. The Census definition of urban is an incorporated place of 2,500 or more inhabitants. Since this definition lumps many small towns under the urban heading, places of 2,500-10,000 inhabitants are also distinguished when examining population characteristics. Additional information is provided on the rural population by distinguishing places with 1,000-2,500 inhabitants. Table I presents urban and rural population characteristics pertaining to transportation need and use.

Of the total rural population, 17.7 percent is sixty years or older. That is 1.4 percent higher than the comparable urban percentage. It is interesting to note that the percent elderly population is highest in places of 2,500-10,000 and of 1,000-2,500, where the percent above 60 years is 23.5 percent and 24.0 percent respectively. The percentage of persons with poverty status is higher in the rural areas where it is 12.4 percent, while it is only 9.3 percent in the urban areas.

The availability of vehicles (including autos, trucks, and vans) to occupied housing units supports the contention that reliance on

TABLE I

OKLAHOMA URBAN AND RURAL POPULATION CHARACTERISTICS: 1980

	Urban		Rural	
	All	Places of 2500-10000	All	Places of 1000-2500
	%	%	%	%
Percent persons 60 years and older	16.3	23.5	17.7	24.0
Percent persons with poverty status, 1979	9.3	13.2	12.4	13.0
Percent housing units with no available vehicle	8.5	11.8	6.4	11.7
Percent housing units with one available vehicle	36.4	35.9	24.0	33.6
Percent housing units, householder 65 years and older with no available vehicle	23.5	25.9	18.4	26.0
Percent of workers using private vehicle to commute	91.3	91.8	89.6	90.7
Percent of workers using public transportation to work	1.3	0.3	0.3	0.2

Source: U.S. Department of Commerce, Bureau of the Census. General Social and Economic Characteristics and Detailed Housing Characteristics, 1980.

private vehicles is greater in rural areas than in urban areas. Eight and one-half percent of the urban housing units have no available vehicles, while only 6.4 percent of the rural housing units have none. It is interesting to note that this percentage climbs to over eleven when looking at places with populations of between 1,000 and 10,000 inhabitants. Data are also given for elderly households where 23.5 and 18.4 percent of urban and rural housing units respectively are without a vehicle. Thirty-six percent of the urban households are considered transportation handicapped because they have only one vehicle available. By comparison, 24 percent of all rural households are transportation handicapped.

Use of public transportation for work commutes is low for all groups examined in Oklahoma. It is highest for the urban population, which would be expected because of greater availability of public transportation in these areas.

As of October 1985, there are eleven rural public transit systems operating with Section 18 funding in over 30 Oklahoma counties. In 1984, in excess of 300,000 passenger trips were provided by six systems. These rural public transportation services are characterized by the use of small transit vehicles such as vans and mini-buses. They typically do not operate on a rigid stop schedule. Fixed routes may be provided on a route deviation basis, allowing for door-to-door service along a predetermined route. Demand responsive services are provided in much the same way as taxi service is provided in larger communities.

Because characteristics of rural public transit are very distinct from those of urban transit, and because of the limited data base on rural transit activities, the need for research in this area is highlighted. As stated in a recent book on transitions in nonmetropolitan America, "...passenger transportation's role in community development, economic development, and social service delivery has been widely recognized but poorly examined on a comprehensive basis" (Saltzmann and Newlin, 1981, p. 281). The recent growth in rural public transit has made important information available which can be examined and utilized when developing new systems, or adjusting service provisions of existing operations for greater efficiency and effectiveness.

Objectives

The main objective of this research is to examine three related aspects of the feasibility of rural public transit in Oklahoma within a planning framework. More specifically, the objectives are to:

1. estimate ridership,
2. demonstrate the development and use of a mileage matrix generator for routing problems, and
3. develop budgeting and performance monitoring guidelines.

Estimations of ridership are made by developing multivariate regression models using data from Section 18 programs in Oklahoma. Estimates are formulated on both a system-wide and route-wide basis. The strength of the models for predictive purposes is tested.

The development of a mileage matrix generator is demonstrated and used in a routing model to solve for the shortest routes in fixed route problems. Applicability is demonstrated with respect to planning for fixed routes, such as nutrition or day care services.

Budgeting guidelines for operating and capital costs of rural transit systems are presented. These guidelines, used in conjunction with predicted levels of ridership, can estimate transit system costs. Subsequent performance guidelines are developed and their use in monitoring programs is discussed. Finally, the use of these tools for feasibility studies in planning future transit activities is examined.

CHAPTER II

ESTIMATION OF RIDERSHIP

Methods of Estimation

Estimation of ridership on public transit is a critical step in the planning process for any system. Ridership affects operational decisions such as vehicle size, type of service provided, and frequency of route provision. The approaches to this planning step vary from subjective analysis to sophisticated modeling.

Subjective analysis expresses a relative need rather than an absolute estimate of ridership. It is often used as a justification for funding instead of as a tool for the planning of service provision. Though this sort of assessment may be easily developed, it does not necessarily represent potential usage.

Gap analysis examines the difference between trips now being made and those that "ought" to be made. Also called latent demand analysis, it can be viewed as measuring unexpressed demand or need. Data on actual trips taken are collected and compared to some level of trip-taking which would exist if more transportation resources were available. This latter measure is often estimated by comparing the community or group under study with a similar group with greater transportation resources. To presume that the population being considered would make more trips if more resources are available implies a change in ridership habits which may or may not be valid.

Aggregate estimates examine the past experience of transit providers and express the expected ridership on a per capita basis. The population as a whole can be used, or it can be segmented on the basis of age or other characteristics. These estimates are simple to use and relatively easy to obtain if similar services are being offered elsewhere, but they ignore the interaction of population and transportation service characteristics.

Regression modeling can be used to estimate ridership based on a variety of variables, such as population characteristics, transit services provided, and availability of other transportation alternatives. Although data requirements of this estimation technique are much higher than other methods, regression is appealing because the approach is more comprehensive.

Review of Previous Studies

Needs Assessment

Some attempts have been made to make the needs assessment of transit demand less qualitative. Burkhardt and Eby (1973) attempted to classify need in terms of purpose, frequency, cost, and destination. The need was then rated as dire, strong, moderate, or slight. No direct estimates of ridership were obtained. Peterson and Smith (1976) developed a goals attainment model, where demand was defined by trip purpose. Trip-taking was found to be overestimated using this method.

Gap Analysis

Yukubousky and Politano (1974) presented a thorough overview of a method for estimating latent demand for travel by elderly, young, and low income individuals in urban and rural areas. They used average travel behavior to estimate latent demand. Burkhardt, Lago, et al. (1976) later pointed out that there is no empirical support for this method.

Aggregate Rates

Peterson and Smith (1976) used a trip generation rate and a participation rate model to estimate demand for rural public transit. Using ridership data from a two county rural public transit system in Wisconsin, a per capita trip rate was calculated for target groups within the service area. Two target groups were identified: elderly and non-elderly low income persons. The non-elderly estimate was improved by using a measure of auto availability rather than estimating people below the poverty level. The participation rate which Peterson and Smith developed stratified the variables used by trip mode, target group, and trip purpose. The estimates produced by these methods had large errors and data were lacking.

Byrne and Neumann (1976) suggested calculation of trip rate by another stratification of the population. They outlined a method for a cross-classification model where trip rates would be determined based on auto availability and household size. No results were presented.

Webb, Doeksen, and Carroll (1981) made an aggregate estimation of a trip rate of 3.01 trips per person per year for the elderly population. This was based on data from 28 projects in rural Oklahoma which were designed to serve the elderly and handicapped. Elderly was defined as 55 years or older.

Modeling

Though their estimates were for cities rather than rural areas, the model developed by Carstens and Csanyi (1968) directed the approach taken by later researchers. Based on data for thirteen cities in Iowa, riders per capita were projected based on the non-worker to worker ratio of the city, population of the city, the average fare, and a service factor. The latter was the ratio of revenue miles of service to the population of the places in the service area. The need to limit the use of this model to cities with similar characteristics was pointed out.

Neuzil (1975) recognized that use was determined by socioeconomic, geographic, and service characteristics. But he proposed that since small urban areas are similar in many respects, the level of service and community size could be used as a determinant of transit use. He calculated a transit service factor defined as annual revenue miles of service divided by the population of the service area. A second order polynomial was fitted for the service factor on rides per capita with a resulting correlation of 0.96. He cautioned that this model should be used to make preliminary estimates only, because of varying characteristics among communities.

Burkhardt, Lago, et al. (1976) developed an idea for modeling particularly suited to rural systems. First, two levels of service were addressed: macro models which examined ridership on a county-wide level, and micro models which examined usage on a sector or route basis. Both levels examined demand responsive services and fixed route services separately, based on the proposition that each kind of service has distinct characteristics which would affect ridership. All models were based on a combination of characteristics of the population, transit service, and availability of competing transit. Data from rural systems in Pennsylvania were used to generate the models. Predictive capabilities were outlined.

Procedure

The intent of this chapter is to estimate ridership for rural public transit for predictive purposes. The multivariate regression approach is taken, because it allows for the consideration of the many factors affecting transit usage. The procedure is based on the study by Burkhardt, Lago, et al. (1976), but differs in some important conceptual and applied ways. These differences will be discussed later.

Data Used

Data were collected from six Section 18 systems serving 19 counties in Oklahoma. The systems offer a mixture of fixed route, demand responsive, and contractual services. Ridership is open to the general public. Data were gathered on a monthly basis starting in June 1983 and terminating in December 1984. Five of the six systems operated for the entire duration; the exception entered the program in 1984. Data collected from the systems included information on ridership, type and extent of service provision, fares, and presence of other transportation services in the area. These data were collected on a monthly basis, and each month was treated as a separate observation. In addition, the Census and Oklahoma Tax Commission were used as sources of information concerning population, income levels, vehicle registration, and population densities. No primary data were collected to determine route or mode preferences or trip purposes. Since the purpose of this portion of the study is to provide a predictive model, only data readily available to transit operators were considered.

Conceptual Model

Estimates of ridership are first developed with an approach which could be termed "macro" or aggregate. Because transit systems used in this study vary from single county to multi-county systems, the macro models are developed in two ways: on a system-wide level and a county-wide level. In the first, observations are recorded which report information for the entire system. Six systems are used in this procedure. In the second method, each observation contains county data, so that some transit systems are broken into their component counties. This is valid, since many systems operate routes primarily within county borders. In addition, each observation is made more comparable, thus avoiding some of the difficulties in modeling for systems with widely varying sizes. Nineteen counties are compared at this level. The macro model is deemed useful for situations where new systems may want to establish in a county, and the potential for ridership from the entire area needs to be estimated. It should be noted that each county and system provides a mix of demand responsive, fixed route, and contracted services. There was no way to separate these on an aggregate level.

In addition to the macro model, a "micro" approach is taken. Two micro models are developed, based on the type of services offered. The approach examines ridership by route for inter-urban fixed route services, and by sector for intra-urban demand responsive services. The two types of services have distinct characteristics which can be taken into account at this level of disaggregation. The fixed route model is developed for routes between communities. In many cases, these routes run from outlying communities into the county seat. The demand responsive models examine sectors which are entirely within town or city boundaries. The micro models are primarily useful for systems wishing to expand or alter the services provided.

At this point it is appropriate to clarify several differences between this research and that of Burkhardt, Lago, et al. (1976). Their model separated fixed route and demand responsive services on the macro scale. Though their approach has the obvious advantage of segmenting similar transit services into distinct models, it was not attempted in this work for several reasons. First, some of the services offered in Oklahoma combined characteristics of both demand responsive and fixed route services. Second, in the use of the macro model for predictions of county-wide or system-wide ridership, no distinction of type of service provision was desired or necessary.

Differences also exist in the micro models. Burkhardt, Lago, et al. (1976) estimated ridership for intra-urban demand responsive services, as well as demand responsive services operating between urban sectors. The latter was only present in the Oklahoma data in one instance. Due to the lack of data, only demand responsive sectors within community limits were modeled in this research.

The final, and perhaps most important difference in the two research efforts is in the populations served. Burkhardt, Lago, et al. (1976) included systems which served a restricted population, based on some eligibility requirements. Therefore they were able to narrowly define the population served. The systems included in the Oklahoma study are open to the general public. Services are not targeted to a more captive market segment, although some specific contracted services are provided for nutrition and day care. Contracted services are considered in the macro model since they reflect potential for transit use. However, in the micro models, contract services are not examined.

Variable Definition and Model Development

The dependent variable in all models is passenger trips. The independent variables reflect demographic characteristics, transit service characteristics, and the availability of other transit services. It would be expected that the number of passenger trips would increase as total, elderly, and/or low income population in an area increased. The expected demand for transit services also would be greater if fewer private vehicles were available to each household. In addition, if more routes and days of service were provided by a transit system, the anticipated ridership would be higher. However, if competing services were offered, this would lower the demand for the transit system under study.

The independent variables examined are defined in Tables II, III, and IV. No consideration of fares was made in the macro models because this information was not available at that level of aggregation. Tests for seasonality were included for the macro models because the observations were distributed among the months so that each season was represented in at least fifteen percent of the observations. This was not possible with the micro models, where the data weighted some seasons more heavily than others. One method of testing for seasonality involved using the variable SUMMER. This allowed for a comparison of summer months versus non-summer months. Another alternative was to test for significance of all four seasons by using the variables SPR, SUM, and FALL.

Table V through Table VIII summarize the values of each variable in the four models: 1) the macro, system-wide model, 2) the macro, county-wide model, 3) the micro, intra-urban demand responsive model, and 4) the micro, inter-urban fixed route model. For each variable, the mean, standard deviation, and the minimum and maximum observed values are given.

Linear regression models were run for both the macro and micro models, as well as log-log transformations. The latter were tried because the relationship between passenger trips and the dependent variables of population and vehicle miles may be perceived as non-linear. Ridership may increase as population and vehicle miles increase, but at a decreasing rate.

TABLE II

MACRO MODEL VARIABLES

Variable Name	Description
SYSPOP	System-wide or county-wide population, depending on the level of aggregation of the macro model. It was estimated annually using preliminary Census reports and projections.
SERPOP1	Sum of populations of incorporated places where the transit system picks up and delivers riders. Estimated annually using preliminary Census reports and projections.
SERPOP2	Sum of populations of incorporated places where the transit system picks up riders. Population of destinations are not included. Estimated annually using preliminary Census reports and projections.
ELDLOW	Elderly and low income population of incorporated places where the transit system picks up riders. Elderly is defined as 55 years or older. Low income is defined as having a standard of living below the poverty level. These two groups are not necessarily exclusive. For places of 2500 or more people the percentages of elderly and low income from the 1980 Census are applied to the population projections to calculate the variable. For places less than 2500, the percentages of elderly and low income in rural portions of the county are applied to the population projections. This variable is intended to identify the population with a high propensity for transit use.
INCOME	Average 1979 income per capita by county.
INCHH	Average 1979 income per household by county.
DENSE	Population density in county, in persons per square mile. Calculated annually.
AUTO	Number of auto, pick-up, and farm truck registrations per household by county.
MILES	Number of vehicle miles of transit service provided per month.

TABLE II (Continued)

Variable Name	Description
FREQ	Frequency of service is proxied by the sum of the number of days each route is run per month.
TAXI	Dummy variable, where 1 indicates the presence of a taxi in the service area.
OTHBUS	Number of other public or human service agency transit vehicles operating in the service area.
SUMMER	Dummy variable, where 1 indicates the month of May, June, July, or August. Used to examine summer observations versus non-summer observations, and never in conjunction with variables SPR, SUM, and FALL.
SPR	Dummy variable, where 1 indicates the month of March, April, or May. Used in conjunction with variables SUM and FALL to examine the variations of four seasons.
SUM	Dummy variable, where 1 indicates the month of June, July, or August. Used in conjunction with variables SPR and FALL to examine the variations of four seasons.
FALL	Dummy variable, where 1 indicates the month of September, October, or November. Used in conjunction with variables SPR and SUM to examine the variations of four seasons.

TABLE III

MICRO MODEL VARIABLES, DEMAND RESPONSIVE SERVICES

Variable Name	Definition
POPSEC	Population of the incorporated place which is served. Estimated annually using preliminary Census reports and projections.
ELDLOW	Elderly and low income population of the sector served. Calculated as described in Table II.
POPLOW	Low income population of sector served, estimated annually as described in Table II.
POPELD	Elderly population of sector served, estimated annually as described in Table II.
PERLOW	Percentage of sector population which is low income, based on 1980 Census.
PERELD	Percentage of sector population which is elderly, based on 1980 Census.
DENSE	Population density of sector in persons per square mile. Calculated annually.
AREA	Land area of sector in square miles.
SRAREA	Square root of the area of sector.
FREQ	Number of days the route is provided per month.
FARE	One way fare per passenger trip in dollars.
TAXI	Dummy variable, 1 indicates the presence of a taxi in sector.
OTH	Dummy variable, 1 indicates the presence of other transit vehicles in sector.

TABLE IV

MICRO MODEL VARIABLES, FIXED ROUTE SERVICES

Variable Name	Definition
POPRTE1	Population of incorporated places along route where riders are picked up. This does not necessarily include the destination.
POPRTE2	Population of incorporated places along route where riders are picked up and the population of the destination of the route.
ELDLOW	Elderly and low income population of incorporated places where riders are picked up. Calculated as described in Table II.
POPELD	Elderly population of incorporated places where riders are picked up. Estimated annually as described in Table II.
POPLOW	Low income population of incorporated places where riders are picked up. Estimated annually as described in Table II.
PERELD	Percentage of elderly population in incorporated places where riders are picked up, based on 1980 Census.
PERLOW	Percentage of low income population in incorporated places where riders are picked up, based on 1980 Census.
POPDEST	Population of city which is destination of route, estimated annually.
GRAV	Gravity variable defined as (POPRTE1 X POPDEST)/DIST^2.
DIST	Round trip mileage of route.
PERMIL	Percentage of total monthly vehicle miles provided by system which are run on the fixed route.
FREQ	Number of days per month the route is run.
FARE	Average one-way fare per passenger trip.

TABLE V

ANALYSIS OF MACRO MODEL VARIABLES, SYSTEM-WIDE BASIS

Variable (n=99)	Mean	Standard Deviation	Minimum	Maximum
SYSPOP	69,550.29	26,432.78	35,267.00	108,775.00
SERPOP1	91,404.20	97,632.86	20,944.00	319,615.00
SERPOP2	34,884.07	7,372.61	20,944.00	47,254.00
ELDLOW	15,839.21	3,099.78	10,101.00	21,888.00
INCOME	5,502.08	689.81	4,573.00	6,472.00
DENSE	27.78	16.31	14.40	58.00
MILES	10,490.39	7,203.82	2,756.00	32,633.00
FREQ	142.88	89.09	22.00	475.00
TAXI	0.82	0.39	0.00	1.00
OTHBUS	1.15	1.47	0.00	3.00
SUMMER	0.35	0.48	0.00	1.00
SPR	0.15	0.36	0.00	1.00
SUM	0.30	0.46	0.00	1.00
FALL	0.33	0.47	0.00	1.00
TRIPS	4,167.43	2,738.09	316.00	13,646.00

TABLE VI

ANALYSIS OF MACRO MODEL VARIABLES, COUNTY-WIDE BASIS

Variable (n=304)	Mean	Standard Deviation	Mininum	Maximum
SYSPOP	21,197.31	14,302.50	4,600.00	48,000.00
SERPOP1	35,530.80	46,751.71	1,281.00	202,733.00
SERPOP2	11,815.06	10,105.22	603.00	37,748.00
ELDLOW	5,437.94	4,121.76	349.00	15,974.00
INCOME	5,376.33	699.93	4,490.00	6,776.00
INCHH	14,264.31	1,668.42	11,989.00	18,260.00
DENSE	22.00	13.40	5.90	58.00
AUTO	1.94	0.20	1.62	2.41
MILES	3,101.04	2,760.79	35.00	21,555.00
FREQ	44.24	26.99	1.00	164.00
TAXI	0.39	0.48	0.00	1.00
OTHBUS	0.42	0.70	0.00	2.00
SUMMER	0.35	0.48	0.00	1.00
SPR	0.17	0.37	0.00	1.00
SUM	0.29	0.46	0.00	1.00
FALL	0.32	0.47	0.00	1.00
TRIPS	1,146.47	885.86	3.00	4,393.00

TABLE VII

ANALYSIS OF MICRO MODEL VARIABLES, DEMAND RESPONSE

Variable (n=191)	Mean	Standard Deviation	Minimum	Maximum
POPSEC	6,943.70	7,284.66	270.00	24,833.00
ELDLOW	3,132.68	2,455.85	118.00	8,887.00
POPLOW	1,348.48	1,147.74	63.72	4,047.78
POPELD	1,783.69	1,359.53	54.00	5,378.06
PERLOW	0.23	0.05	0.13	0.33
PERELD	0.30	0.08	0.16	0.43
DENSE	1,541.86	735.76	273.00	2,645.00
AREA	5.53	6.65	0.80	27.50
SRAREA	2.01	1.21	0.90	5.20
FREQ	19.66	4.22	1.00	24.00
FARE	0.45	0.10	0.33	0.72
TAXI	0.25	0.43	0.00	1.00
OTH	0.11	0.31	0.00	1.00
TRIPS	590.84	643.15	0.00	3,393.00

TABLE VIII

ANALYSIS OF MICRO MODEL VARIABLES, FIXED ROUTE

Variable (n=117)	Mean	Standard Deviation	Minimum	Maximum
POPRTE1	3,833.31	5,554.70	144.00	24,303.00
POPRTE2	22,132.32	26,501.65	3,293.00	97,798.00
ELDLOW	1,865.75	2,919.11	76.00	12,973.00
POPELD	1,010.33	1,520.61	38.38	6,659.02
POPLOW	855.90	1,406.78	37.30	6,318.78
PERELD	0.25	0.04	0.20	0.34
PERLOW	0.22	0.05	0.11	0.26
POPDEST	18,299.01	24,906.31	3,137.00	91,449.00
GRAV	19,554.58	31,668.41	601.76	118,410.49
DIST	72.07	53.45	12.00	250.00
PERMIL	0.06	0.07	0.00	0.47
FREQ	5.08	4.00	1.00	20.00
FARE	1.41	0.77	0.50	3.50
TRIPS	54.83	57.52	2.00	313.00

Models and variables were initially assessed on several criteria. The multiple correlation coefficient, or R^2, was examined as it reflects the proportion of the variance in ridership which is explained by the independent variables. A higher value of R^2 was preferred, although it was only one of several selection criterion used.

Parameter estimates were assessed using a t-test for significance at the 5 percent level. The t-value is calculated for the null hypothesis that the parameter estimate equals zero. In addition, the F-value for Type III sums of squares was found to be significant at the 5 percent level. The Type III sums of squares specifies the contribution of that variable to the model if it were the last one added. In other words, it is the contribution of that variable above and beyond all the others.

Using these tests of the statistical significance of the model and the estimated coefficients, two or three "best" models were chosen. It was verified that the signs of the parameter estimates had a logical meaning. If the models were intended to be purely descriptive, then the above tests would be sufficient for developing the model definition. However, an objective of the models is their use as forecast tools. Therefore, it is necessary to test further for accuracy of forecasts.

Testing Accuracy of Forecasting Models

Testing the accuracy of forecasting models can be approached in several manners. First, the 1983 and 1984 data used to develop the models can be substituted into the models to generate predicted trip estimates. These can then be compared to the actual trips taken. The alternative method is to develop another data set of the model variables, and use this data in each model to generate predictions. Thus, data other than those which were used to build the model are used for testing. This latter method was performed by using a data set with observations for 1985 from the same transit systems, as well as from a new system. Using the variables observed in the 1985 data set, and the parameter estimates generated using 1983 and 1984 data, a set of predictions of ridership are developed. These forecasts are compared to the observed ridership in the 1985 data set.

Comparisons of predicted and actual values can be made in a number of ways. These will be discussed briefly. A_i is the actual number of passenger trips made for the i^{th} observation. P_i is the predicted number of trips made for the i^{th} observation. The number of observations made is given by n.

A simple test is to count the number of negative predictions. Preference is given to models which have few or no negative predictions, i.e. no negative number of passenger trips. A negative number of trips lacks interpretive value.

The mean absolute error (MAE) may be calculated as shown in equation 2.1. The mean absolute error examines the average of the absolute value of the residuals. It can be considered superior to the mean error, since large positive and large negative errors do not cancel each other (Maddala, 1977; Pindyck and Rubinfeld, 1981).

$$MAE = \frac{1}{n}\sum_{i}^{n} |A_i - P_i| \qquad (2.1)$$

The proportion of absolute errors (PAE), as shown in equation

2.2, gives the proportion that the absolute value of the residuals are of the actual trips made. Like the mean absolute error, this measure has the advantage that large negative and positive errors do not cancel each other (Burkhardt, Lago, et al., 1976).

$$PAE = \frac{\sum_{i}^{n} |A_i - P_i|}{\sum_{i}^{n} |A_i|} \tag{2.2}$$

The root mean square error (RMS), specified in equation 2.3, gives a measure of the deviation of the predicted variable from its actual value. A smaller RMS indicates better model performance (Pindyck and Rubinfeld, 1981).

$$RMS = \sqrt{\frac{1}{n} \sum_{i}^{n} (A_i - P_i)^2} \tag{2.3}$$

Theil's inequality coefficient, or Theil's U, is a statistic which falls between zero and one. The calculation of this statistic is shown in equation 2.4. If perfect forecasts were made, then U=0 indicating that $P_i = A_i$ for all observations. If U=1, then the predictive performance of the model is the worst it can be (Maddala, 1977).

$$U = \sqrt{\frac{\sum_{i}^{n} (P_i - A_i)^2}{\sum_{i}^{n} A_i^2}} \tag{2.4}$$

Theil's U can be further decomposed into three other proportions of inequality: the bias proportion, the variance proportion, and the covariance proportion (Pindyck and Rubinfeld, 1981). The bias proportion (U^M) is examined because it indicates a systemic error in the model. It is defined as shown in equation 2.5. The bias proportion measures to what extent the mean actual observations deviate from the mean predicted outcomes. The closer that U^M is to zero, the smaller the systemic bias.

$$U^M = \frac{(\overline{A} - \overline{P})^2}{\frac{1}{n} \sum_i^n (A_i - P_i)^2} \qquad (2.5)$$

It should be noted that none of these measures consider what will happen to the actual observations given an exogeneous shock. Rather, they are calculated given the model with its specified variables and parameter estimates to examine the predictive capabilities of the model.

Results

Macro Model

As might be expected, the macro model using data aggregated to the system-wide level gave results which were inferior to those given by data aggregated on a county-wide basis. Only the county-wide models will be discussed.

Using the criteria specified above, two models (equations 2.6 and 2.7) were identified: one linear and one using a log-log transformation. They are defined in Table IX. The linear equation (2.6) generates estimates using the population variable which includes only the population of places which originate ridership. Additional socio-demographic variables include income per household

TABLE IX

SUMMARY OF MACRO MODEL EQUATIONS FOR ESTIMATION OF RIDERSHIP[a]

Equation 2.6[b]		Equation 2.7[c]	
Variables		Variables	
SERPOP2	0.0351 (0.0001)	LOG SERPOP2	0.2899 (0.0001)
MILES	0.1408 (0.0001)		
FREQ	7.5935 (0.0010)	LOG FREQ	1.1888 (0.0001)
INCHH	-0.1003 (0.0004)		
OTHBUS	-325.4280 (0.0001)		
SUMMER	-190.2434 (0.0074)		
AUTO	-824.6981 (0.0001)	LOG AUTO	-1.3208 (0.0026)
INTERCEPT	3196.7091 (0.0001)	INTERCEPT	0.5796 (0.1732)
Evaluation Statistics		Evaluation Statistics	
R^2	0.5802	R^2	0.7120
N	304	N	304

[a]Parameter estimates are listed, followed by the significance level (in parenthesis) as determined by the t-test value.

[b]The dependent variable is passenger trips per month.

[c]The dependent variable is the log of passenger trips per month.

and auto registrations per household. The transit service variables include the number of vehicle miles of service, the frequency of service, and the presence of other transit vehicles serving that area. In addition, there is significantly lower ridership in the summer months. Equation 2.6 has an R^2 of 0.5802.

The log-log model uses the same population variable as the linear model. Other significant variables are frequency of service and vehicle registrations per household. Equation 2.7 has an R^2 value of 0.7120.

These equations were specified after some initial trials which had inferior results. The initial runs included trips, vehicle miles, and route frequencies for services provided on Head Start routes. Upon examination of residual plots, it was found that heteroskedasticity existed. The error variance increased as the frequency of service increased. Upon closer examination, it was determined that each observation in this higher frequency range was in a county which provided Head Start transportation. It was decided that since Head Start ridership was already easily predicted from enrollment figures, the trips, frequency, and mileage data which represented these rides would be eliminated from the data set.

To choose between the models, their predictive capabilities were examined as shown in Table X. Although Equation 2.7 has a higher multiple correlation coefficient, Equation 2.6 performs better on a predictive basis. All the measures of error for the linear equation are lower than those for the log-log equation, except the number of negative predictions. However, since their differences in predictive capabilities are small, the log-log transformation in Equation 2.7

TABLE X

MACRO COUNTY-WIDE MODELS, TESTS FOR PREDICTIVE CAPABILITIES

Measure	Equation 2.6	Equation 2.7
Negative Predictions (count)	1.000	0.000
Mean Absolute Error	520.785	534.893
Proportion of Absolute Error	0.400	0.411
Root Mean Square Error	685.757	837.590
Theil's U	0.426	0.521
Bias Proportion	0.005	0.053

may be chosen because of its relative simplicity in use.

Micro, Demand Responsive Models

Three demand responsive models were specified. These equations are presented in Table XI. Equation 2.8 generates a trip estimate from low income population, elderly population, and the square root of the area of the sector served. This has the highest R^2 value of 0.803. Equation 2.9 uses the population of the sector served and the number of days of service per month. The resulting multiple correlation coefficient is 0.693. The final model generates estimates based on the population of the sector served, the percentage of low income persons, and the number of days of service per month. The latter is significant at the 10 percent level. The proportion of variation explained by equation 2.10 is 0.763

Log transformations were analyzed, but all had inferior results. The variable for fares did not come in as significant. This may be due to the lack of variation in the variable. However, with federal subsidies decreasing for transit, fares may be raised to defray operational costs. In the future, further analysis of the effect of fares on ridership should be pursued.

The predictive capabilities of the models were examined, and the results presented in Table XII. All models indicate a systemic bias in predictions, with Equation 2.9 demonstrating the smallest bias. Because of this, and because Equation 2.9 gives the smallest number of negative predictions, this equation is preferred over the others.

TABLE XI

SUMMARY OF MICRO, DEMAND RESPONSIVE MODEL EQUATIONS FOR ESTIMATION OF RIDERSHIP[a]

	Equation 2.8[b]	Equation 2.9[b]	Equation 2.10[b]
Variables			
POPSEC		0.0711 (0.0001)	0.0882 (0.0001)
POPLOW	0.4355 (0.0001)		
POPELD	0.1310 (0.0013)		
PERLOW			4,010.5655 (0.0001)
SRAREA	-98.5136 (0.0008)		
FREQ		12.8973 (0.0453)	9.3545 (0.0997)
INTERCEPT	-31.8202 (0.4411)	-156.7625 (0.2087)	-1,109.7829 (0.0001)
Evaluation Statistics			
R^2	0.8029	0.6928	0.7631
N	191	191	191

[a]Parameter estimates are listed, followed by the significance level (in parenthesis) as determined by the t-test value.

[b]The dependent variable is passenger trips per month.

TABLE XII

MICRO MODEL, DEMAND RESPONSIVE SERVICES,
TESTS FOR PREDICTIVE CAPABILITIES

Measure	Equation 2.8	Equation 2.9	Equation 2.10
Negative Predictions (count)	17.000	3.000	15.000
Mean Absolute Error	212.594	224.561	231.970
Proportion of Absolute Error	0.350	0.369	0.381
Root Mean Square Error	340.021	418.594	410.277
Theil's U	0.355	0.437	0.429
Bias Proportion	0.162	0.085	0.130

Micro, Fixed Route Models

Using the relative R^2 values and tests for significance of variables, the two fixed route models shown in Table XIII were developed. Independent variables used in Equation 2.11 include the population of the destination of the route, the round trip distance of the route, and the percentage of total vehicle miles provided by the system which are run on the fixed route. The resulting R^2 value is 0.682. In Equation 2.12, ridership is estimated using a different population variable--the population of both the destination and the origins of the route. The other variables are the same as those in the previous equation.

Log transformations were attempted, but again none gave superior results. Fares did not appear as a statistically significant variable. Lack of variation among routes may explain this result.

Results of the tests for predictive capabilities are shown in Table XIV. Equation 2.11 performs slightly better than Equation 2.12, although the bias indicated is comparable. Equation 2.11 is the preferred model for forecasting trips on an inter-urban fixed route.

Application of Models to Estimate Ridership

To demonstrate the use of the ridership estimation models, a hypothetical example will be presented. A county-wide rural transit system has been proposed for Fairview County. Estimates of ridership are desired for the entire county and for the components of service. Demand responsive services will operate in the county seat of

TABLE XIII

SUMMARY OF MICRO, FIXED ROUTE MODEL EQUATIONS FOR ESTIMATION OF RIDERSHIP[a]

	Equation 2.11[b]	Equation 2.12[b]
Variables		
POPDEST	0.0006 (0.0002)	
POPRTE2		0.0006 0.0014
DIST	-0.2720 (0.0002)	-0.3098 (0.0001)
FREQ	7.7072 (0.0001)	7.8860 (0.0001)
PERMIL	139.0134 (0.0316)	129.9211 (0.0481)
INTERCEPT	15.3869 (0.0181)	16.7718 (0.0122)
Evaluation Statistics		
R^2	0.6820	0.6715
N	117	117

[a]Parameter estimates are listed, followed by the significance level (in parenthesis) as determined by the t-test value.

[b]The dependent variable is passenger trips per month.

TABLE XIV

MICRO MODEL, FIXED ROUTE SERVICES, TESTS FOR PREDICTIVE CAPABILITIES

Measure	Equation 2.11	Equation 2.12
Negative Predictions (count)	1.000	6.000
Mean Absolute Error	27.235	28.200
Proportion of Absolute Error	0.489	0.507
Root Mean Square Error	43.806	44.930
Theil's U	0.466	0.478
Bias Proportion	0.017	0.011

Limelight on weekdays. On the average, this will result in 21 days of service per month. It is estimated that 50 vehicle miles per day will be run for the demand responsive services.

Three rural routes are proposed to run from outlying communities into the city of Limelight. Route One will serve the towns of Moore and Movin on a round trip of 80 miles. The second route will be 72 miles round trip, and serve Somer, Source and Short. The final route will serve three towns: Clinton, Clearwell and Cargo. Round trip mileage for Route Three is 65 miles. Each of these routes will run into Limelight one day per week, for an average of four trips per month. Population characteristics are given in Table XV. No other transit vehicles currently operate in Fairview County, and estimates are desired for only non-summer months.

Calculation of ridership estimates can be performed on a step-by-step basis. First, the value of the model variable is calculated according to its definition. Second, the product of the variable values and their respective parameter estimates are summed. This total is the estimate of ridership per month. Table XVI presents this process for the macro estimate using Equation 2.6. An estimated 1,458 trips may be generated in the county per month.

In Table XVII, the calculation of the estimate for the demand responsive service is given. The projection of rides per month for a demand responsive system in Limelight is 648. The fixed route projection for Route One is shown in Table XVIII. Fifty-two rides are projected for this route on a monthly basis. In a similar manner, projections for Routes Two and Three could be made. These would be 52 trips per month, since the effect of the decrease in the

TABLE XV

POPULATION CHARACTERISTICS FOR EXAMPLE APPLICATION OF TRIP ESTIMATION MODELS

Characteristics	Value
Population of towns:	
Limelight	7,508
Moore	800
Movin	2,745
Somer	3,043
Source	275
Short	587
Clinton	960
Clearwell	292
Cargo	2,600
County income per household	13,900
Vehicle registrations per household	1.85

TABLE XVI

WORKSHEET FOR MACRO ESTIMATES, EXAMPLE

Variable		Calculation	
SERPOP2	:	Sum populations of places where riders are served. 7,508 + 800 + 2,745 + 3,043 + 275 + 587 + 960 + 292 + 2,600	= 18,810
MILES	:	Total vehicle miles per month. Sum the products of daily route mileage and number of days of service per month for each route. Demand Responsive 50 X 21 = 1,050 Route 1 80 X 4 = 320 Route 2 72 X 4 = 288 Route 3 65 X 4 = 260 TOTAL	1,918
FREQ	:	Sum the number of days each route is run per month. Demand Responsive 21 Route 1 4 Route 2 4 Route 3 4 TOTAL	33
INCHH	:	County income per household from Census.	13,900
OTHBUS	:	Number of other public transit vehicles operating in area.	0
SUMMER	:	Dummy variable, where 1 indicates the month of May, June, July, or August.	0
AUTO	:	Number of auto, pick-up, farm truck registrations by county.	1.85

TABLE XVI (Continued)

Ridership Estimate Calculation (Based on Equation 2.6)

Variable	Value	X	Parameter Estimate	=	Value Added to Estimate
INTERCEPT	(given)			=	3,196.7091
SERPOP2	18,810	X	0.0351	=	660.2310
MILES	1,918	X	0.1408	=	270.0544
FREQ	33	X	7.5935	=	250.5855
INCHH	13,900	X	- 0.1003	=	-1,394.1700
OTHBUS	0	X	-325.4280	=	0.0
SUMMER	0	X	-190.2434	=	0.0
AUTO	1.85	X	-824.6981	=	-1,525.6915
ESTIMATE--TRIPS PER MONTH					1,457.7185

TABLE XVII

WORKSHEET FOR DEMAND RESPONSIVE ESTIMATES, EXAMPLE

Variable Calculation				
POPSEC	:	Population of sector served.	=	7,508
FREQ	:	Number of days per month demand responsive services are provided.	=	21

Ridership Estimate Calculation (Based on Equation 2.9)					
Variable	Value	X	Parameter Estimate	=	Value Added to Estimate
INTERCEPT	(given)			=	-156.7625
POPSEC	7,508	X	0.0711	=	533.8188
FREQ	21	X	12.8973		270.8433
ESTIMATE--TRIPS PER MONTH					647.8996

TABLE XVIII

WORKSHEET FOR FIXED ROUTE ESTIMATES,
EXAMPLE FOR ROUTE ONE

Variable Calculation

POPDEST	:	Population of destination.	=	7,508
DIST	:	Round trip mileage of route.	=	80
FREQ	:	Number of days per month the route is run.	=	4
PERMIL	:	Percentage of total monthly vehicle miles provided by the system which are run by this fixed route.		
		Total monthly miles = 1,918		
		Total monthly miles of route = 320		
		320 ÷ 1,918	=	.1668

Ridership Estimate Calculation (Based on Equation 2.11)

Variable	Value	X	Parameter Estimate	=	Value Added to Estimate
INTERCEPT (given)				=	15.3869
POPDEST	7,508	X	0.0006	=	4.5048
DIST	80	X	-0.2720	=	-21.7600
FREQ	4	X	7.7072	=	30.8288
PERMIL	.1668	X	139.0134	=	23.1874
ESTIMATE--TRIPS PER MONTH					52.1479

round trip mileage of the routes offsets that of the decrease in the value of the variable PERMIL.

It may be useful to generate a range of values for the estimates. This could be done by adding and subtracting the mean absolute error from the projected estimates. The values of the mean absolute errors are given in Tables X, XII and XIV.

Examination of the demand estimates can lead to important decisions regarding fleet capacity and route scheduling. For instance, on the fixed routes, if 52 one-way rides are generated monthly and occur evenly throughout the month, a van seating 13 passengers would be of sufficient size. In addition, it is indicated that route operation on a weekly basis will satisfy the ridership projections.

CHAPTER III

ROUTING

Introduction

For some transportation problems, efficient routing of vehicles is an important consideration. Public services such as municipal solid waste collection, postal delivery, and school bus pick-ups require routing which will minimize mileage while considering vehicle capacity and fleet size. Public transit is another area where vehicle scheduling and route development play an important role in operational efficiency. In some situations, scheduling of public fixed routes to serve clusters or concentrations of population is needed. Other uses of routing may involve a more defined demand, such as provision of transportation to an elderly nutrition program. In this case, route stops would be clearly defined. But because of changes in participation levels, frequent rerouting may be necessary.

In general, there are several goals of a routing program. These include minimization of route mileage and time, reduction of fleet size, or reallocation of routes so as to allow for a change in vehicle size. These goals are often translated into cost reductions, although safety, scheduling, and reduced wear on vehicles may also be considerations.

Constraints on route operation may exist, such as route time, unsatisfactory road and bridge conditions, and vehicle capacity. In addition, routing problems can be defined in a variety of ways: with multiple origins and destinations, with a single origin and multiple destinations, or with many origins and a single destination.

The intent of this chapter is to first review previous approaches to routing problems. Recognizing the need in many route programs for a mileage matrix giving the shortest distance from each point to every other point, an efficient shortest path algorithm was identified. An example of the use of this algorithm and a routing program are presented.

Selected Review of Previous Studies

The study of routing crosses many disciplines, and as a result, the approaches to the problem and goals in solutions vary widely. A brief overview of some of these studies is included here.

The "traveling salesman" problem, as it is commonly termed, is a problem where the shortest path passing through all given points once and only once is found. In addition, the route begins and ends in the same location. Dantzig and Ramser (1959) used a procedure based on a linear programming formulation to solve a traveling salesman problem. The input in this procedure was a matrix of shortest paths between any two points. A near optimal solution for a routing problem could be obtained. No practical applications were made.

A later study by Lin (1969) also addressed the traveling salesman problem. Two algorithms were studied, one of which could computationally handle large solutions and produce locally optimal solutions. The latter used a heuristic approach believed by the author to be of general applicability (Lin, 1969, p. 2247). Though the programs were copywritten, computational results and times were given for various size cities. It was proposed that the choice of routing algorithms be based on maximizing the probability that among locally optimal solutions there was the optimal solution.

Bodin and Berman (1979) grouped routing procedures into two approaches. The route-first-cluster-second approach solves the traveling salesman problem first, and then breaks this chain into routes which are feasible given vehicle and time constraints. The cluster-first-route-second approach involves preliminary clustering of nodes that could be feasible routes. Then routing is performed within the node clusters.

Bodin and Berman (1979) used the first procedure in two school bus routing studies. They used procedures developed by Lin (1969) to solve for a route through all bus stops. Then two heuristics were used to divide the route into component parts. If a route was over capacity at a particular stop, the program looked ahead to see if the next stop could be added instead. Then a new route was started at the previous node. Another decision rule was that if the next stop resulted in an excess of capacity, but the load at that last stop was at least ten percent of vehicle capacity, then the stop would be split into two bus stops. These steps were used to split the initial route into smaller routes, which were then reviewed in a scheduling framework. Cost savings and the increase in the number of students transported were presented for two school districts.

Angel, Caudle, Noonan and Whinston (1972) used the cluster-first-route-second approach in a school bus routing problem. The input data included a shortest path matrix between all points, data on bus capacity, and the number of students per stop. Bus stops were grouped on the basis of proximity using a clustering algorithm. Within the cluster, routes were then determined using a traveling salesman algorithm.

Several authors developed modifications of a routing procedure presented by Clarke and Wright (1964). In this procedure it is initially assumed that there is a vehicle to serve every node i and j. A decision rule is then applied which pairs nodes on one route so that the cost savings will be the greatest among all possible choices. The savings is represented by:

$$S_{ij} = C_{oi} + C_{jo} - C_{ij} \tag{3.1}$$

where:

S_{ij} = the savings associated with linking nodes i and j on the same route,

C_{oi} = the least cost from the origin node to node i,

C_{jo} = the least cost from node j to the destination, and

C_{ij} = the least cost from node i to node j.

Initially, the cost of running two vehicles to i and j respectively is $2C_{oi} + 2C_{jo}$. By combining node i and j on the same route, $C_{oi} + C_{jo}$ is saved and the cost C_{ij} is incurred. Thus, equation 3.1 is defined. Nodes are combined on the same route according to the largest S_{ij} found, as long as no capacity restrictions are violated, and all nodes are still connected to the origin. Costs may be measured in mileage, time, or a weighted combination of both. A cost or distance matrix from each node to every other node is needed as input for a solution. The procedure is heuristic in nature.

Clarke and Wright (1964) considered only the symmetric solution, where the destination and origin were the same. Bennett and Gazis (1972) extended the procedure so that asymmetrical solutions could be obtained, and routes could be reversed. In addition, they presented a modified objective function where bus travel time and student travel time were considered separately. The purpose of this was to increase travel safety by lowering actual student travel time. Results were presented for a New Jersey school district.

Hallberg and Kriebel (1972) also used the Clarke and Wright (1964) procedure for delivery route systems. They noted a number of restrictions to be handled in the model. These involved: specifying type of vehicle, scheduling timing of delivery, and restricting number of operating hours, vehicle capacity, or number of stops per route. Other restrictions, such as driving speeds, one-way streets, and road quality, could be considered in the calculation of the cost measures. A Fortran computer program called ROUTE was presented which incorporated the solution procedures discussed.

Data Needs and Development

A Shortest Path Algorithm

As can be seen, many routing programs require a distance matrix which presents the shortest distance from each node to every other node. Given a symmetrical distance matrix, for n nodes there are $n(n-1)/2$ distances in this matrix. For smaller problems, this matrix may be generated by hand. But as the number of nodes under consideration increases, the cost of developing this matrix increases exponentially. In addition, the potential for human error increases.

This led to a search for an efficient shortest path algorithm which would generate the necessary matrix. One such procedure reviewed was by SAS (Statistical Analysis System Institute, 1983). Input data required were distances between adjacent nodes, and identification of source and sink nodes. The program was primarily for directed network programs and could be modified for minimum and maximum flow problems. The procedure was found to be too costly for large problems.

An algorithm in Baase (1978) was adopted, which is based on the algorithm outlined by Dijkstra in Numerische Mathematik (1959, pp. 269-271). It was programmed using the language PL1, and was found to perform expediently on large problems.[1]

The procedure outlined by Dijkstra is to solve for the path of minimum length between two nodes X and Z. It is given that nodes Y are on the shortest path between the origin X and destination Z. The branches connecting to Y are labeled y. The minimum paths from X to all other nodes are constructed until the destination is reached.

The nodes and the distances between them are grouped into three sets each. The node sets are called A, B, and C, and the branch sets are labeled I, II, and III. In Set A are the nodes for which the minimum path from the origin is known. Initially Set A is empty, and nodes will be added to it in order of increasing minimum distances

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[1]Programming efforts are credited to James Alexander and Shari McClure.

from node X. Set B contains all nodes that are connected to at least one node in Set A, but are not in Set A. Set C contains the remaining nodes.

Set I contains all branches occurring in the minimal path from node X to the nodes in Set A. Set II contains the branches from which the next branch to be placed in Set I will be selected. These are the branches under consideration. Set III contains the branches not yet considered.

To start, all nodes are in Set C and branches in Set III. Then the origin node is placed in Set A. The first step is to consider all branches connecting the last node entered in Set A with any other node in Set B or Set C. If the node under consideration is in Set C, it is moved to Set B and its respective branch is moved to Set II. If the nodes Y which connect to the last node in Set A are in Set B, then further investigation takes place. If the branch y gives a shorter path from X to Y than the known path using the corresponding branch in Set II, then it moves into Set II. If not, it remains in Set III.

The second step considers that every node in Set B can be connected to the origin node X in only one way if the choice of branches is restricted to Sets I and II. Therefore, every node Y in Set B has a distinct distance from node X. The node Y with the minimum distance from the origin is placed in Set A, and the respective branch is moved to Set I.

These steps are repeated until the destination node Z is transferred into Set A. Then the solution for the shortest path from node X to node Z has been found. It should be noted that nodes and branches move in one direction through the sets, from C to B to A, and III to II to I, respectively. To solve for the shortest path from each node to every other node, two loops in the shortest path program are performed. The first solves for one origin to all destinations, and the second loop counts all origins. The time and cost savings of generating a shortest path matrix using the Dijkstra algorithm are considerable. For an example routing problem which had 102 nodes, the entire mileage matrix originally required n(n-1)/2 or 5,151 pieces of data. Because the shortest path program generates this matrix using only the distances between adjacent nodes, the number of pieces of data required as input were reduced to 361. The full 102 X 102 matrix was generated in less than one minute. Tests were performed to verify that the identical distance matrix was generated.

Example of Shortest Path Algorithm

To understand Dijkstra's approach to finding the shortest path between two points, an example is given to demonstrate the step-by-step procedure which was outlined in Numerische Mathematik, (1959). The example has six nodes numbered one through six. The possible paths or branches between nodes are given by the dotted lines in Figure 1. Distances between nodes are given in parentheses. The problem is to find the shortest distance between nodes one and six.

Initial Situation. There are three sets of nodes and three sets of branches. A branch and its associated distance is given by the

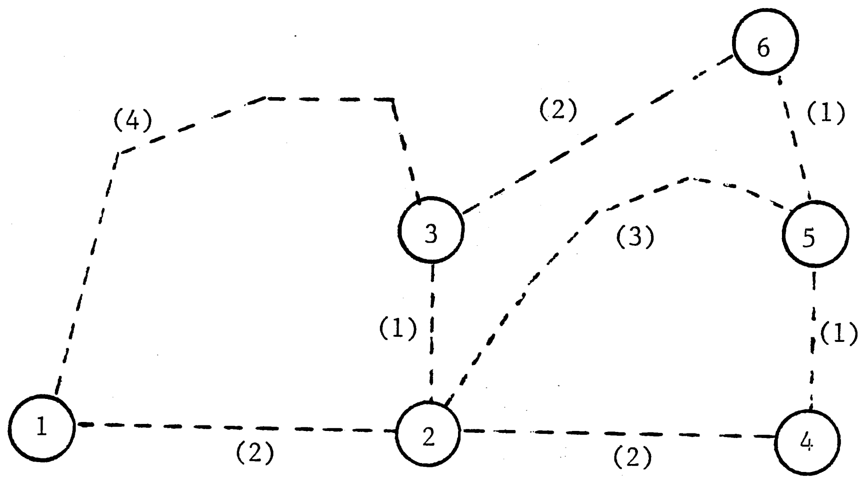


Figure 1. Example for Shortest Path Algorithm

following notation: 1-2(2). This indicates that the branch runs from node one to node two and has a distance of two. Initially, all nodes are in Set C and all branches are in Set III. Then, node one is placed in Set A. The first step is to consider all the branches connecting node one to the nodes in Set B or C. These are 1-2(2) and 1-3(4). Nodes two and three are in Set C, so they are placed in Set B and the respective branches are placed in Set II. This is shown in step one, Table XIX. In the second step, it is determined that node two has the minimum distance from node one. Node two is placed into Set A and the respective branch moved to Set I, as shown in step two of Table XIX.

Second Iteration. In the first step, all branches connecting node two with nodes in either Set B or Set C are considered. These include 2-3(1), 2-4(2), and 2-5(3). Node three is in Set B, so the branch 2-3(1) is investigated to determine if it yields a shorter path from node three to node one than the path already in Set II, which is 1-3(4). Since it does, 2-3(1) is placed in Set II and 1-3(4) is rejected. The other nodes considered are nodes four and five. These are in Set C, so they are moved to Set B and their respective branches are moved to Set II, as shown in step one of Table XX. To complete the second step, consider that the nodes in Set B have only one distance to node one, using the branches in Set I and Set II. The minimum distance is from node three to node one passing through node two. Therefore, node three is moved to Set A and branch 2-3(1) is moved to Set I. This is depicted in step two of Table XX.

TABLE XIX

SHORTEST PATH ALGORITHM, INITIAL SITUATION

Step One

Nodes

Set A	1
Set B	2, 3
Set C	4, 5, 6

Branches

Set I	
Set II	1-2(2), 1-3(4)
Set III	2-3(1), 2-4(2), 2-5(3), 3-6(2), 4-5(1), 5-6(1)

* * * * * * * * * * * * * * *

Step Two

Nodes

Set A	1, 2
Set B	3
Set C	4, 5, 6

Branches

Set I	1-2(2)
Set II	1-3(4)
Set III	2-3(1), 2-4(2), 2-5(3), 3-6(2), 4-5(1), 5-6(1)

TABLE XX

SHORTEST PATH ALGORITHM,
SECOND ITERATION

Step One

<u>Nodes</u>

Set A	1, 2
Set B	3, 4, 5
Set C	6

<u>Branches</u>

Set I	1-2(2)
Set II	2-3(1), 2-4(2), 2-5(3), 1-3(4)
Set III	3-6(2), 4-5(1), 5-6(1)

* * * * * * * * * * * * * * *

Step Two

<u>Nodes</u>

Set A	1, 2, 3
Set B	4, 5
Set C	6

<u>Branches</u>

Set I	1-2(2), 2-3(1)
Set II	2-4(2), 2-5(3), 1-3(4)
Set III	3-6(2), 4-5(1), 5-6(1)

Third Iteration. In the first step, consider all the branches connecting node three to any other node in Set B or Set C. There is only one, 3-6(2). Node six, which is in Set C, is moved to Set B and the respective branch is moved to Set II. This is shown in step one of Table XXI. The nodes in Set B have only one distance to node one, using the branches in Set I and Set II. The minimum distance is from node four to node one, passing through node two. Therefore, node four is moved to Set A and branch 2-4(2) is moved to Set I, as shown in step two, Table XXI.

The selection process continues as described. The solution to this problem is found when node six is moved to Set A. The problem can be expanded, as it is when used to generate a mileage matrix, to find the shortest path from each node to every other node.

Application of Shortest Path Algorithm and Routing Procedure

To demonstrate the use of the shortest path algorithm and a routing procedure, an hypothetical situation will be reviewed. There is a nutrition site operating in a rural portion of Fairview County. Transportation to this site is needed for 29 residents living in rural areas. The transportation system in the county would like to contract to provide these services with a fifteen-passenger vehicle. The shortest routes to pick up the passengers must be determined, as well as scheduling information.

First, the location of the residents is plotted on a county map,

TABLE XXI

SHORTEST PATH ALGORITHM, THIRD ITERATION

Step One

Nodes

Set A	1, 2, 3
Set B	4, 5, 6
Set C	null

Branches

Set I	1-2(2), 2-3(1)
Set II	2-4(2), 2-5(3), 3-6(2), 1-3(4)
Set III	4-5(1), 5-6(1)

* * * * * * * * * * * * * * *

Step Two

Nodes

Set A	1, 2, 3, 4
Set B	5, 6
Set C	null

Branches

Set I	1-2(2), 2-3(1), 2-4(2)
Set II	2-5(3), 3-6(2), 1-3(4)
Set III	4-5(1), 5-6(1)

as shown in Figure 2. In addition, node 19 was identified as the nutrition site. Since the riders are elderly, door-to-door service will be provided. For this example, it is assumed that there is only one person residing at each stop.

Second, a mileage matrix must be generated. Since there are 30 nodes, there will be 435 distances in the mileage matrix. By using the shortest path program described previously, only the distances between the adjacent nodes are needed as input. For this example, eighty-six adjacent nodes were identified. The distances between adjacent nodes were measured by hand from the map. The input data, shortest path program, and matrix output are shown in the Appendix in Tables XXXIII, XXXIV, and XXXV respectively.

The mileage matrix, vehicle capacity data, and origin identification were input into the routing program defined by Hallberg and Kriebel (1972) known as ROUTE. The program generated the two routes shown in Figures 3 and 4.

Route One serves 14 passengers on as many stops. The round trip distance of the route is 36.7 miles. At an estimated average driving speed of 30 miles per hour, driving time would total 73.4 minutes. If three minutes are allotted for each boarding, the route would take 115 minutes to run, or nearly two hours. A summary of Route One is made in Table XXII.

Route Two is shorter, although 15 passengers are served. The total mileage of the route is 28.05. At an average speed of 30 miles per hour, the driving time would total 56.1 minutes. Allowing three minutes per stop, the route would run for approximately 101 minutes. Route Two is summarized in Table XXIII.

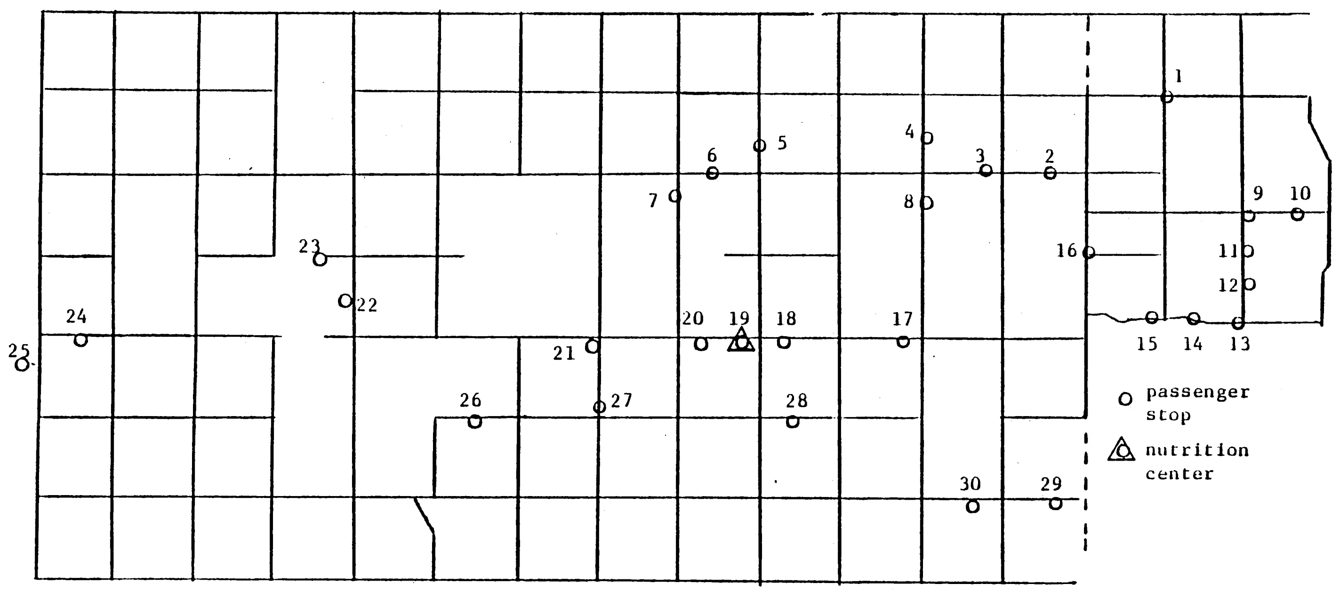


Figure 2. Locations of Residents Needing Transportation

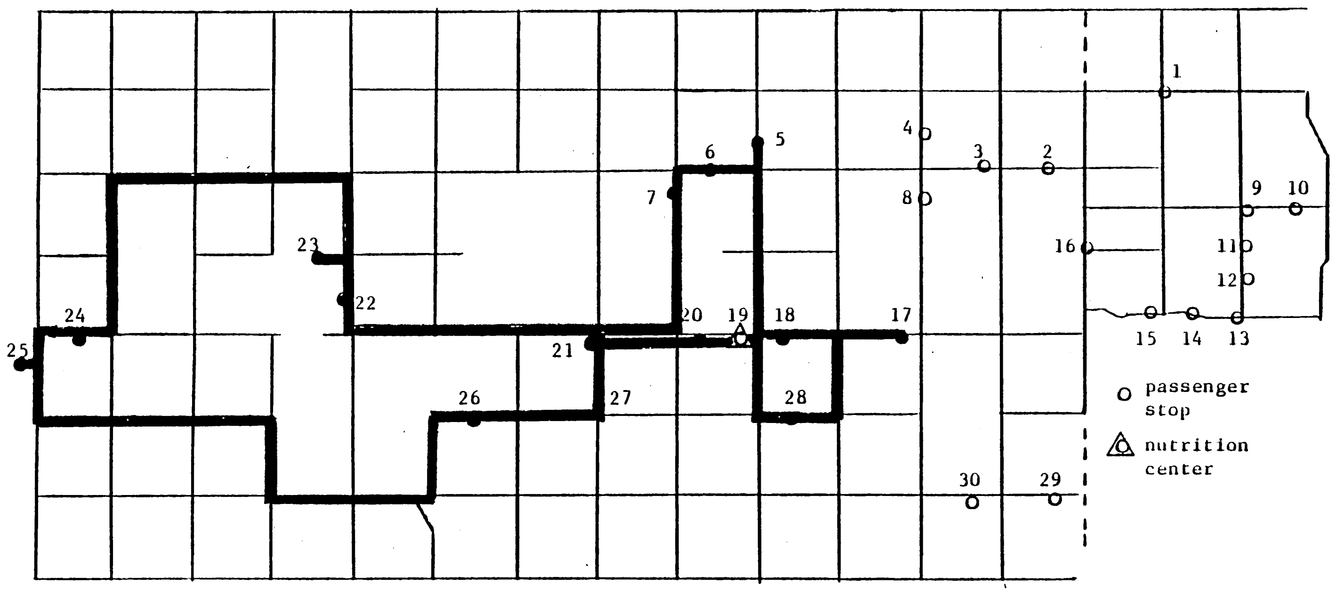


Figure 3. Example Nutrition Route, Route One

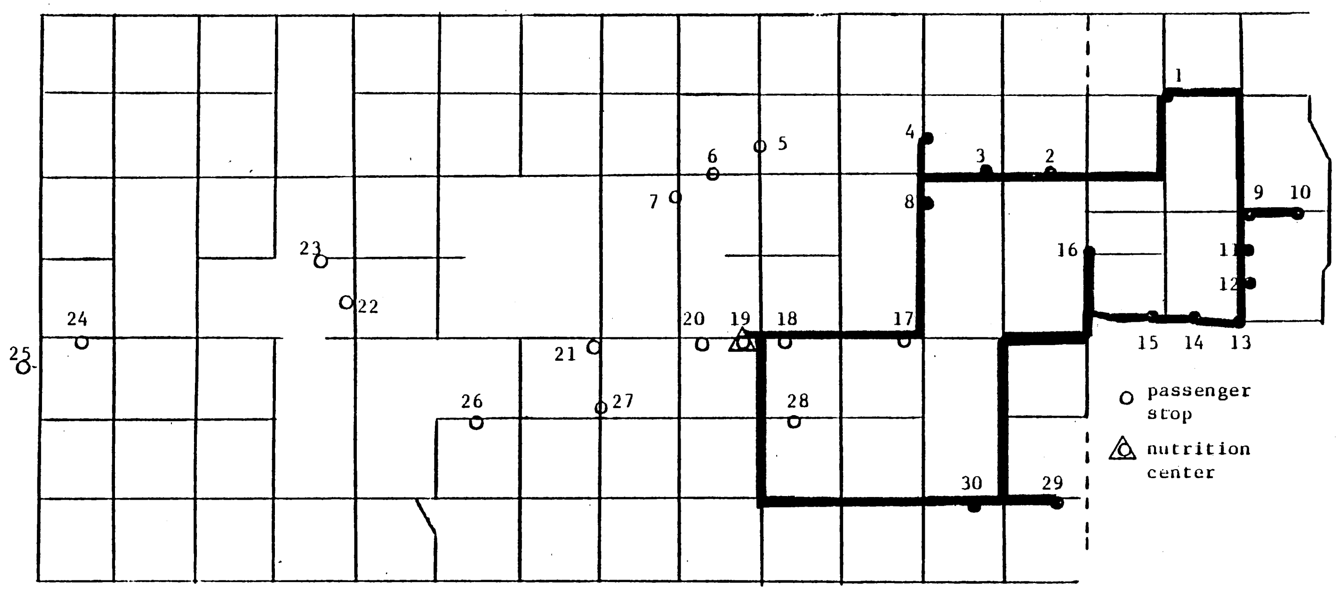


Figure 4. Example Nutrition Route, Route Two

TABLE XXII

SUMMARY OF ROUTE ONE

Stop Number	From	To	Distance	Driving Time	Passenger Load
	(node)	(node)	(miles)	(minutes)	(people)
1	19	28	1.65	3.3	1
2	28	17	2.35	4.7	1
3	17	18	1.45	2.9	1
4	18	5	2.75	5.5	1
5	5	6	0.95	1.9	1
6	6	7	0.70	1.4	1
7	7	22	5.75	11.5	1
8	22	23	0.90	1.8	1
9	23	24	6.80	13.6	1
10	24	25	1.00	2.0	1
11	25	26	8.10	16.2	1
12	26	27	1.65	3.3	1
13	27	21	0.85	1.7	1
14	21	20	1.30	2.6	1
15	20	19	0.50	1.0	--
TOTAL			36.70	73.4	14

TABLE XXIII

SUMMARY OF ROUTE TWO

Stop Number	From	To	Distance	Driving Time	Passenger Load
	(node)	(node)	(miles)	(minutes)	(people)
1	19	8	3.85	7.7	1
2	8	4	0.85	1.7	1
3	4	3	1.35	2.7	1
4	3	2	0.75	1.5	1
5	2	1	2.40	4.8	1
6	1	10	3.20	6.4	1
7	10	9	0.60	1.2	1
8	9	11	0.60	1.2	1
9	11	12	0.40	0.8	1
10	12	13	0.50	1.0	1
11	13	14	0.60	1.2	1
12	14	15	0.50	1.0	1
13	15	16	1.75	3.5	1
14	16	29	4.80	9.6	1
15	29	30	1.00	2.0	1
16	30	19	4.90	9.8	--
TOTAL			28.05	56.1	15

If only one vehicle is used to provide both of these routes, some riders may have to wait while the alternate route is run. If the nutrition program lags meal services, this may be acceptable. Alternatively, local decisionmakers may choose to make two vehicles available to run the described routes.

CHAPTER IV

BUDGETING AND MONITORING FOR RURAL PUBLIC TRANSIT

Introduction

In transit planning, the development of efficient and effective transportation services is a multi-faceted process. Once the type and level of service provision is defined, the service area determined, and demand estimates and routes are identified, then the budgeting process begins. Accurate estimates of capital, administrative, and operating costs are needed to verify financial feasibility before a system initiates operation. After preliminary budget estimates are made, adjustments can be made to a system's operational plan if necessary.

During the budget period, monitoring should take place to assure that activities remain within the financial limitations of the system. This monitoring activity, or performance evaluation, examines how successfully a system is meeting its goals. The type of performance guidelines used will vary depending on the transit system goals. If the objective is to minimize costs of a level of service, then costs per vehicle mile or costs per passenger trip may be examined. If ridership maximization is the primary goal of the transit service, then a performance guideline such as passenger trips per vehicle hour may yield important information.

In addition to monitoring goal achievements, cost measures such as fuel and maintenance costs per vehicle mile provide a vital feedback loop to the budgetary process. Continual monitoring of a system allows for budget refinements. In this way, budgeting and performance evaluation are an interactive process.

These ideas are foundations of successful transit management. For rural transit, this foundation has a limited data base. Rural public transit has a young history and as a result, budget and performance evaluation guidelines are not well established. The intent of this chapter is to first present budgeting guidelines developed from Oklahoma operations. Then, a review of literature on performance monitoring will be made. The development of performance guidelines for Oklahoma rural public transit programs will be presented, and finally, an example of their use will be given.

Budgeting Guidelines.

Capital Costs

The capital costs considered are for vehicles and communication equipment. Although garage facilities are desirable, they are typically not available. Cost estimates of a fifteen-passenger van, several sizes of mini-buses, and very-high-frequency (VHF) and ultra-high-frequency (UHF) communication equipment are given in Table XXIV. All cost estimates are in 1985 dollars. The vehicle costs are based on bid awards given through the Oklahoma Department of Transportation in 1984 and 1985. Awards given in 1984 were adjusted to 1985 dollars based on the Consumer's Price Index for Transportation. The eleven-passenger vehicle with one wheel chair

TABLE XXIV

CAPITAL EQUIPMENT COSTS

Item	Cost[a]
Van	
15-passenger van, 125" wheel base	$14,700
Mini-Bus, (Light Transit)	
11-passenger with lift and one wheel chair lock	$26,540
16-passenger	$20,785
17-passenger	$22,640
17-passenger with lift and two wheel chair locks	$33,215
Communication Equipment	
VHF radio	$ 880
UHF radio	$ 980
VHF base (depending on range)	$900 - $ 1,075
UHF base	$ 1,125

[a]All costs are in 1985 dollars. Costs reported in 1984 were indexed to 1985 dollars by the CPI for transportation.

lock and lift is comparable to the seventeen-passenger vehicle without modifications for the handicapped.

Estimates of communication equipment costs are based on both bid awards and information provided by communication equipment dealers. All costs were adjusted to 1985 dollars based on the Consumer's Price Index for Transportation. There is a large range of capabilities of both base stations and radios that must be recognized when estimating these costs. Given transit system needs and geographic characteristics of the service area, communication costs may be either higher or lower than indicated. Radio tower costs are not included, because most operators rent space on community towers.

For planning purposes, capital equipment may be depreciated over its life expectancy. Vehicles may have a life of 75,000-125,000 miles, depending on maintenance programs, vehicle load, and condition of roads traveled. Communication equipment life expectancy is ten years.

Operating Costs

Estimates of operating and administrative costs are presented in Table XXV. These cost estimates are based on information obtained in interviews with six Oklahoma rural public transit system operators, in addition to data from 1984-1985 budget reports for the same six operations, and guidelines established in previous research (Webb, Doeksen and Carroll, 1981). All cost estimates were adjusted to reflect 1985 dollars using the 1985 Consumer's Price Index for Transportation.

Gasoline, maintenance, and insurance costs are dependent in part

TABLE XXV

OPERATING AND ADMINISTRATIVE COST ESTIMATES

Item	Cost
Gasoline, per gallon	$1.25
Van (15-passenger), 9 mpg	
Mini-Bus, 7 mpg	
Maintenance	
Oil and Lubrication, every 4,000 miles	$30
Tune-up	
Van, every 15-20,000 miles	$45
Mini-bus, every 10-15,000 miles	$50
Tires	
Van, every 18,000 miles, per set	$360
Mini-bus, every 15,000 miles, per set	$400
Miscellaneous	
Van, every 10,000 miles	$340
Mini-bus, every 10,000 miles	$460
Insurance, per vehicle	$1,200
Driver (plus 25% benefits), per hour	$4.25
Secretary (plus 25% benefits), per hour	$4.00
Director (plus 25% benefits), per year	$16,000
Office supplies, per year	$1,300
Advertising, per year	$2,000
Rent, per year	$3,600
Telephone, per year	$1,600
Utilities, per year	$1,200
Audit, per year	$1,000
Travel and Miscellaneous, per year	$1,700
Communication, per radio, per month	$10
Other costs to consider:	
Dispatch	
Route supervisor	
Licensing and Tags	

on type of vehicle, and number of vehicle miles driven. Operators reported obtaining seven miles per gallon of gasoline with mini-buses, and nine miles per gallon with vans. Maintenance schedules varied among operators and vehicle types. In general, vans required maintenance at less frequent intervals and at lower costs than did mini-buses. Insurance averaged approximately $1,200 per vehicle. Vehicle licensing and tags must also be considered, but vary so widely that estimates should be made on a case-by-case basis.

Labor cost averages are presented for drivers and secretaries at an hourly rate, since hours of operation vary among transit systems. The average director's salary was approximately $16,000 per year. Benefits must be added to all labor costs, and are valued at approximately 25 percent. Labor costs for dispatchers and route supervisors may be considered, depending on the size of the system and the types of services offered.

Additional expenses for office supplies, advertising, rent, telephone, utilities, audit, and travel and miscellaneous are listed in Table XXV. These are averages based on annual budget reports. They may be adjusted to more closely reflect a particular transit system's needs and situation. For instance, a new system may wish to allow more for advertising than a well established system. These capital and operating cost guidelines can be used to develop budgets by persons who are initiating or expanding service options.

Review of Selected Performance Evaluation Literature

Much of the literature in the area of transit performance evaluation examines the alternative methods of using time-series data for individual systems versus cross-sectional data for peer comparisons. Alternative approaches used in either urban or rural transit systems are reviewed. In addition, performance evaluation measures which were developed particularly for rural transit systems are presented.

Miller and Kirby (1984) presented a study on two rural transit systems in Minnesota. One was a route deviation service and the other a van pool service for commuters. Based on a five year study period and discounting to 1979 dollars, the total cost per passenger trip was $1.17 for both systems. The route deviation system had a cost per trip mile of $0.43, while the van pool system reported $0.05. Revenue generated per passenger trip was $0.30 for the route deviation system, and $0.48 for the van pool. The study suggested presenting performance evaluation results with information regarding population, ridership, and eligible users, so that system characteristics were apparent. However, the authors advised the use of time-series data to track individual systems rather than the use of cross-sectional data (p. 43).

In a study by Vaziri and Deacon (1984), the problems of peer comparisons between transit systems were acknowledged. In spite of these, peer comparisons were justified by the contention that although all systems do not have the same performance level, all systems with similar characteristics should have the same potential for performance. By using factor and cluster analysis, peer groups were formed and target performance levels were set at the group average. Urbanized areas were used for the aggregation level.

Kelley and Rutherford (1983) also developed peer groups for comparative performance analysis. The peer groups were developed for transit systems in the State of Washington and based on the size of the service area of each system. Time-series analysis was used in conjunction with peer group comparisons to identify outlyers.

An alternative approach to comparison of mean performance measures within peer groups was presented in two related studies by Mundle and Cherwony (1980) and Hobeika, Kanok-Kantapong and Tran (1984). In the Mundle and Cherwony study, the expected performance of a peer group consisting of New York City bus depots was developed using regression analysis. Regression analysis generated an individualized expected performance value based on system characteristics. In a similar manner, Hobeika, Kanok-Kantapong, and Tran (1984) used regression analysis to explain the level of transit performance through selected independent variables in Section 15 data. For example, regression analysis was used to explain expenses, passenger fare revenue, and passenger trips. Then, using data from individual transit systems, expected values of performance were generated. A performance index for each performance measure was calculated by dividing the difference between the actual and expected performance by the expected performance. Systems were then ranked based on the index values.

Talley and Becker (1982) maintained that transit routes should be used as the basis for evaluation. They defined the transit deficit per passenger as a performance measure which considers a positive contribution to a system rather than a minimum standard. The transit deficit measure allows for the evaluation of two goals:

maximization of ridership and minimization of the cost of providing service for a given level of ridership.

Two other studies presented calculations of transit performance measures for rural systems. Koushki and Berg (1982) studied a fixed route, fixed schedule transit service which shuttled between two New York towns with institutions of higher education. In seven and one-half months, 12,307 rides were provided. Seven runs were made between the towns each day. The average cost per passenger trip ranged from $1.28 to $2.13 depending on the time of day the route was run (p. 637).

Burkhardt (1983, p. 5) presented ranges for several performance measures based on data from over 100 Section 147 projects. These included: total cost per passenger trip at $2.15 to $8.10, total cost per vehicle mile at $0.65 to $1.35, total cost per vehicle hour at $8.35 to $24.25, load ratio at 6 to 35 percent, and revenue divided by operating and administrative costs at $0.25 to $1.00. In addition, 0.12 to 0.30 passenger trips per mile and 2.2 to 6.0 passenger trips per vehicle hour were taken.

Development of Performance Guidelines for Oklahoma Rural Transit Systems

Introduction

There are several important considerations to make when preparing performance measures for transit systems. Most measures are presented in a ratio format, such as ratios to level of service provision or to a percentage of costs. This allows for comparisons both within a system and among systems as both endogeneous and exogeneous changes occur.

Care must be taken to assure that reported items, such as costs, represent the same thing regardless of the system reporting. For example, operating costs typically include administrative costs such as a director's and secretary's salary. However, under Section 18 reporting methods, the administrative and operating costs are reported separately due to different reimbursement procedures. The performance measures presented here use this distinction between operating and administrative costs since the transit systems reviewed are Section 18 programs.

Another example of misleading data is in the reporting of handicapped trips. Since no standard definition of handicapped has been developed for transit operators, this statistic may be reported in a number of ways. Some operators consider the handicapped category to be exclusive of the elderly. Others consider any person needing assistance boarding a vehicle as handicapped. In the latter situation, a passenger may be counted as both elderly and handicapped. This occurred in the Oklahoma data.

Several other considerations may be made for cost data. First, lumpy costs such as insurance and capital purchases should be allocated over the time period to which they accrue. For the measures calculated in this research, this information was not available. As a result, insurance costs were averaged over all reported months. Capital costs were not included in the cost ratios.

A final cost consideration can be made when the study period spans many years. In this situation, the costs may be indexed so that they are expressed in constant dollars. The costs presented in the performance evaluation portion of this research have not been indexed unless noted. For the purpose of this research, use of constant dollars in performance measures was not considered necessary.

Data Used

Data were reported by eight Section 18 transit systems serving 24 counties in Oklahoma. They included trip statistics and budget information reported on a monthly basis. Trip statistics included vehicle miles, vehicle hours, seat miles, passenger miles, passenger trips, elderly trips, and handicapped trips. Budget data included farebox revenue and total administrative and total operating costs, as well as insurance, advertising, fuel and oil, maintenance, driver, route supervisor, and dispatch expenses. Missing data and unreliable data were eliminated from mean calculations. Reports of a zero value were included in averages.

Results

Table XXVI lists the low, high, and mean value of each performance measure calculated for all eight systems. As can be seen, some measures exhibit considerable variation among systems. Others, such as fuel expense per vehicle mile, show a great deal of uniformity.

Often, there is an outlyer in the group which distorts the range, so there appears to be greater variability than actually exists. In order to give greater detail, Table XXVII presents four common effectiveness measures by system, with the mean and standard

TABLE XXVI

PERFORMANCE GUIDELINES GENERATED FROM EIGHT RURAL SYSTEMS

Measure	Low	High	Mean[a]
Effectiveness			
Passenger Trips/Month	428.00	7,605.00	3,590.00
Elderly Trips/Total Trips	0.00	0.78	0.54
Handicapped Trips/Total Trips[b]	0.03	1.00	0.26
Passenger Trips/Vehicle Mile	0.10	0.78	0.42
Passenger Trips/Vehicle Hour	2.38	7.57	4.14
Efficiency			
Passenger Miles/Seat Miles	0.03	0.52	0.17
Passenger Miles/Passenger Trip[c]	2.39	39.51	12.92
Operating Expense/Vehicle Mile	0.36	1.11	0.85
Administrative & Operating Expense/ Vehicle Mile	0.63	1.75	1.30
Operating Expense/Passenger Trip	1.29	7.40	3.00
Administrative & Operating Expense/ Passenger Trip	1.99	13.73	4.88
Fare Revenue/Passenger Trip	0.00	0.53	0.29
Fare Revenue/Operating Expense	0.00	0.22	0.13
Fare Revenue/Administrative & Operating Expense	0.00	0.13	0.08
Fuel Expense/Vehicle Mile	0.11	0.15	0.14
Maintenance Expense/Vehicle Mile	0.02	0.24	0.07

TABLE XXVI (Continued)

Measure	Low	High	Mean[a]
Driver Expense/Operating Expense	0.46	0.81	0.64
Labor Expense/Operating Expense	0.57	0.83	0.73
Fuel Expense/Operating Expense	0.13	0.36	0.18
Maintenance Expense/Operating Expense	0.03	0.24	0.08
Driver Expense/Administrative & Operating Expense	0.30	0.53	0.42
Advertising Expense/Administrative & Operating Expense	0.00	0.01	0.01
Insurance Expense/Administrative & Operating Expense	0.01	0.07	0.04

[a]Mean is calculated for all systems exclusive of those with missing data.

[b]Measure includes observation of one system which counts an elderly person as both elderly and handicapped.

[c]Measure is of particular importance for demand responsive systems.

TABLE XXVII

EFFECTIVENESS MEASURES, FOR EIGHT OKLAHOMA SYSTEMS

System	Passenger Trips/Month Mean	Passenger Trips/Month Standard Deviation	Elderly Trips/Total Trips Mean	Elderly Trips/Total Trips Standard Deviation
A	2,540.3	272.7	0.78	0.11
B	5,924.8	1,244.1	0.69	0.16
C	428.0	273.5	0.00	0.00
D	7,605.3	4,154.6	0.18	0.16
E	5,093.5	1,652.2	0.59	0.19
F	2,741.0	950.5	0.66	0.12
G	2,915.5	387.6	0.66	0.08
H	1,470.4	213.1	0.78	0.04

System	Passenger Trips/Vehicle Mile Mean	Passenger Trips/Vehicle Mile Standard Deviation	Passenger Trips/Vehicle Hour Mean	Passenger Trips/Vehicle Hour Standard Deviation
A	0.33	0.06	2.87	0.64
B	0.78	0.10	7.57	4.33
C	0.10	0.06	2.38	1.50
D	0.31	0.14	3.81	2.38
E	0.36	0.12	3.46	0.96
F	0.57	0.08	4.93	0.57
G	0.57	0.08	NA	NA
H	0.34	0.04	3.98	0.43

deviation for each. Data in Table XXVIII present four common efficiency measures.

Use of Performance Measures

The calculation of performance measures is, for the most part, a relatively simple task. The difficulty is in their application. As stated by Sindzinski (1984):

> Measures, per se, do not judge performance. Rather they provide some basic information that must be put into a context that assesses whether the system is operating efficiently and effectively...the trap is quite simply that numbers are merely information and not answers (p. 11).

Although a wide array of performance measures are presented in this study, a transit system should choose only those which relate to measuring its goals. Then, two approaches may be taken. First, a system can examine how its performance changes over time. Second, a comparison may be made among transit systems with similar characteristics.

If peer comparisons are made with the Oklahoma data, unique characteristics of each system must be considered. Except for system C, all of these rural transit programs are currently providing a mixture of both demand responsive and fixed route services. System A and system E are in areas of the state which have particularly long distances between towns, which affects the vehicle miles traveled. Several systems generate large proportions of their revenue from contracted services. This revenue is not included in the farebox revenue, and so the revenue collected per dollar administrative and operating expense appears low. Operations such as system D should

TABLE XXVIII

EFFICIENCY MEASURES, FOR EIGHT OKLAHOMA SYSTEMS

System	Cost[a]/Vehicle Mile Mean	Cost[a]/Vehicle Mile Standard Deviation	Cost[a]/Passenger Trip Mean	Cost[a]/Passenger Trip Standard Deviation
A	1.75	0.40	5.42	1.44
B	1.52	0.41	1.99	0.62
C	0.63	0.10	13.73	13.87
D	1.11	0.35	5.41	6.30
E	1.13	0.24	3.36	1.06
F	1.61	0.29	2.83	0.17
G	1.37	0.21	2.43	0.49
H	1.29	0.28	3.87	0.84

System	Fare Revenue/Dollar Cost[a] Mean	Fare Revenue/Dollar Cost[a] Standard Deviation	Passenger Miles/Seat Miles Mean	Passenger Miles/Seat Miles Standard Deviation
A	0.10	0.03	0.24	0.17
B	0.08	0.05	0.14	0.05
C	0.00	0.00	0.32	0.08
D	0.06	0.03	0.52	0.10
E	0.09	0.05	0.19	0.06
F	0.08	0.02	0.16	0.04
G	0.13	0.04	0.06	0.02
H	0.13	0.03	0.16	0.05

[a]Cost includes administrative and operating costs.

calculate another measure to reflect those contracted revenues.

Because of variations among systems and the small sample used in the calculation of these performance measures, it is advisable that only persons with a thorough knowledge of the systems involved make specific deductions regarding a particular system's performance. (To preserve each transit system's anonymity, further characteristic identification is avoided here.) Mean values of the performance measures may be used as preliminary reference points.

More importantly, transit systems should monitor themselves continually, and analyze changes in performance which are relevant to their goals. Plots of performance measures over time can be a revealing tool to a transit system. Trends can be analyzed by examining the component parts of the measure.

After exploring these performance measures, appropriate actions must be taken. Usually, either an increase in ridership or a decrease in costs may be determined necessary. Ridership actions may involve marketing changes, adjustments in fare policy, or service improvements. Cost reductions may be originated from within current production practices, or may require a long term change.

Finally, performance measures can be used by transit systems to refine budget projections. Measures such as fuel cost per vehicle mile, maintenance cost per vehicle mile, and labor cost per vehicle hour can assist in budget formulation even if service levels are adjusted in subsequent years. Documentation of a previous year's performance provides a vital link to the upcoming year's planning process.

Application of Budgeting Guidelines and Performance Evaluation

Use of Budgeting Guidelines

To demonstrate the use of budgeting guidelines, capital and operating budgets will be developed for the hypothetical example presented in Chapter II. A 1983 and 1984 van are available for use in the county. Although these may be sufficient to provide the three rural routes and demand responsive services in Limelight, planners wish to purchase an additional fifteen-passenger van. This will allow the use of the older vehicle as a back-up. Communication equipment will be installed in each vehicle. Because the system will operate within the county, VHF radios are determined to have sufficient range. Capital needs are presented in Table XXIX. A capital budget which reflects a sinking fund is presented in Table XXX. Allowances for depreciation of capital equipment are made annually. These may be placed in a sinking fund for future replacement. Vehicles are depreciated over 100,000 miles, and communication equipment over ten years. A straight line depreciation method has been used.

As presented previously, a total of 1,918 vehicle miles will be run per month, or approximately 23,016 miles per year. A full-time director will be hired, and be assisted by a full-time secretary/dispatcher. One full-time driver will be responsible for the demand responsive services. An additional driver will be hired for 20 hours per week to drive the rural routes. The calculations of annual fuel, maintenance, and labor costs are presented in Table

TABLE XXIX

EXAMPLE CAPITAL NEEDS

Item	Cost
Van, 15-passenger	$14,700
VHF radios (3)	$ 2,640
VHF base station	$ 1,000
TOTAL CAPITAL COSTS	$18,340

TABLE XXX

EXAMPLE CAPITAL SINKING FUND BUDGET

Item		Depreciation Allowance
1983 Van (back-up)		
$13,800 value ÷ 100,000 miles = $.138 per mile		
$.138 per mile X 800 miles per year	=	$ 110.40
1984 Van		
$14,200 value ÷ 100,000 miles = $.142 per mile		
$.142 per mile X 10,016 miles per year	=	$1,422.27
1985 Van (new)		
$14,700 value ÷ 100,000 miles = $.147 per mile		
$.147 per mile X 12,200 miles per year	=	$1,793.40
Communication Equipment		
$3,640 value ÷ 10 years	=	$ 364.00
TOTAL ANNUAL DEPRECIATION ALLOWANCE		$3,690.07

XXXI. The preliminary operating budget has been developed in Table XXXII for the first year of operation.

Use of Performance Evaluations

Since the Fairview County transit system has yet to come into existence, an example evaluation using data collected in Oklahoma will be made. System D in this research project will be the operation under evaluation. Suppose system D was monitoring operating costs per passenger trip in order to provide the basis for changes in fare policies. Operating costs per passenger trip were plotted in Figure 5 for easier consideration. It is apparent that summer months show higher values for this measure than other months. Because air conditioning units in the vehicles have been costly maintenance items, this may explain an increase in operating costs in the summer. Maintenance costs as a percent of total operating costs are presented in Figure 6. This seems to explain some increase in operational costs, but not enough to warrant the large increase in operating costs per passenger trip which is experienced during the summer. Other operating costs are explored with no pertinent findings.

Next, passenger trips are plotted in Figure 7. It is obvious from this plot that ridership drops dramatically in summer months. Operators of system D should consider reasons for this. Perhaps transportation needs change in the summer months, and thus warrant a change in routes. Additional marketing efforts such as special fares may be needed to promote summer ridership. Or, if ridership reductions are anticipated in the summer months, compensating

TABLE XXXI

EXAMPLE CALCULATION OF FUEL, MAINTENANCE, AND LABOR COST

Operating Cost		Total
Fuel		
(23,016 van miles ÷ 9 mpg) X $1.25/gallon	=	$ 3,196.70
(0 bus miles ÷ 7 mpg) X $1.25/gallon	=	0
Oil and Lubrication		
(23,016 miles ÷ 4,000) X $30	=	$ 172.60
Tune-Up		
(23,016 van miles ÷ 15,000) X $45	=	$ 69.05
(0 bus miles ÷ 10,000) X $50	=	0
Tires		
(23,016 van miles ÷ 18,000) X $360	=	$ 460.30
(0 bus miles ÷ 15,000) X $400	=	0
Miscellaneous		
(23,016 van miles ÷ 10,000) X $340	=	$ 782.55
(0 bus miles ÷ 10,000) X $460	=	0
Director		
$16,000 annual salary X 1.25 (benefits)	=	$20,000.00
Drivers		
60 hrs/week X 52 X $4.25 per hour X 1.25 (benefits)	=	$16,575.00
0 hrs/week X 52 X 0 per hour X 1.25 (benefits)	=	0
Secretary		
40 hrs/week X 52 X $4.00 per hour X 1.25 (benefits)	=	$10,400.00

TABLE XXXII

EXAMPLE OPERATING AND ADMINISTRATIVE BUDGET

Item	Cost
Fuel	$ 3,196.70
Maintenance	1,484.50
Insurance	3,600.00
Drivers	16,575.00
Secretary	10,400.00
Director	20,000.00
Office Supplies	1,300.00
Advertising	2,000.00
Rent	3,600.00
Telephone	1,600.00
Utilities	1,200.00
Audit	1,000.00
Travel and Miscellaneous	1,700.00
Communication	360.00
Licensing and Tags (estimate)	380.00
TOTAL OPERATING AND ADMINISTRATIVE COSTS	$68,396.20

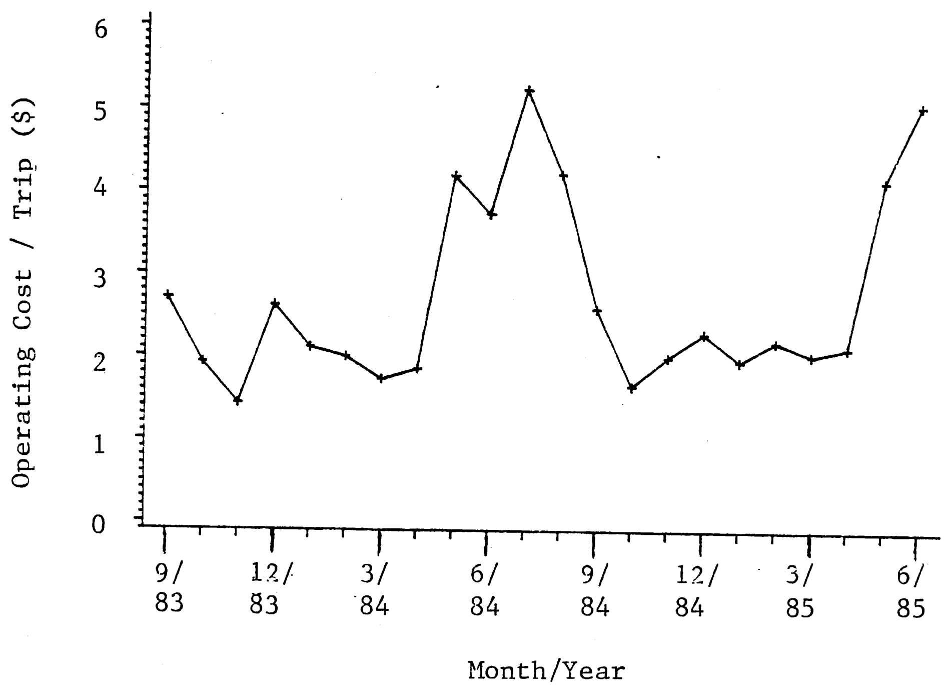


Figure 5. Operating Cost Per Passenger Trip

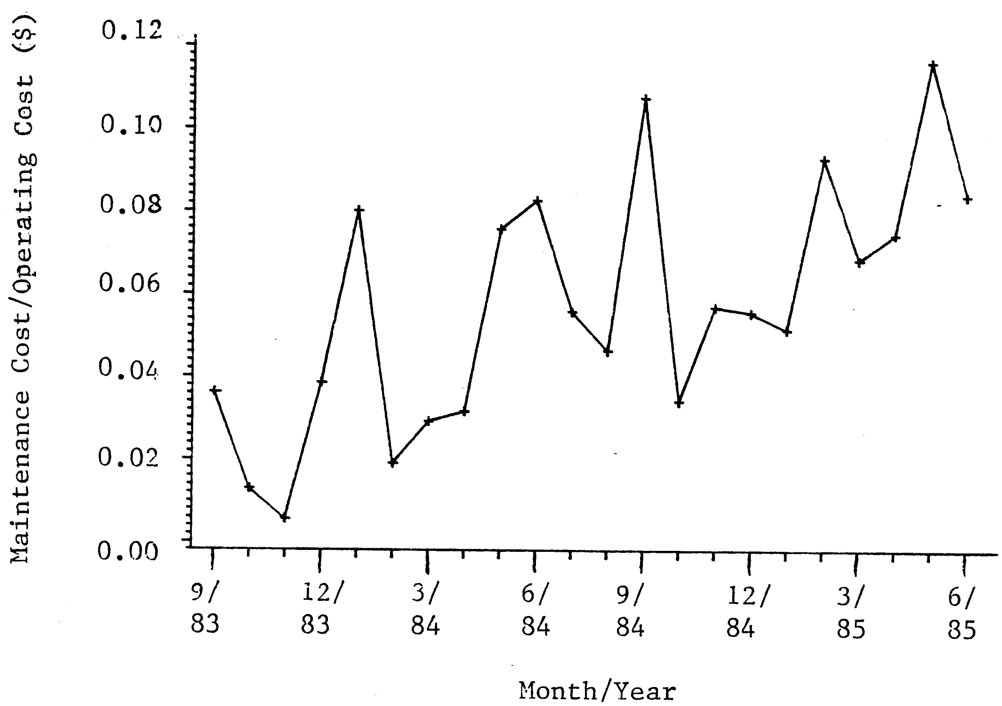


Figure 6. Maintenance Cost Per Dollar Operating Cost

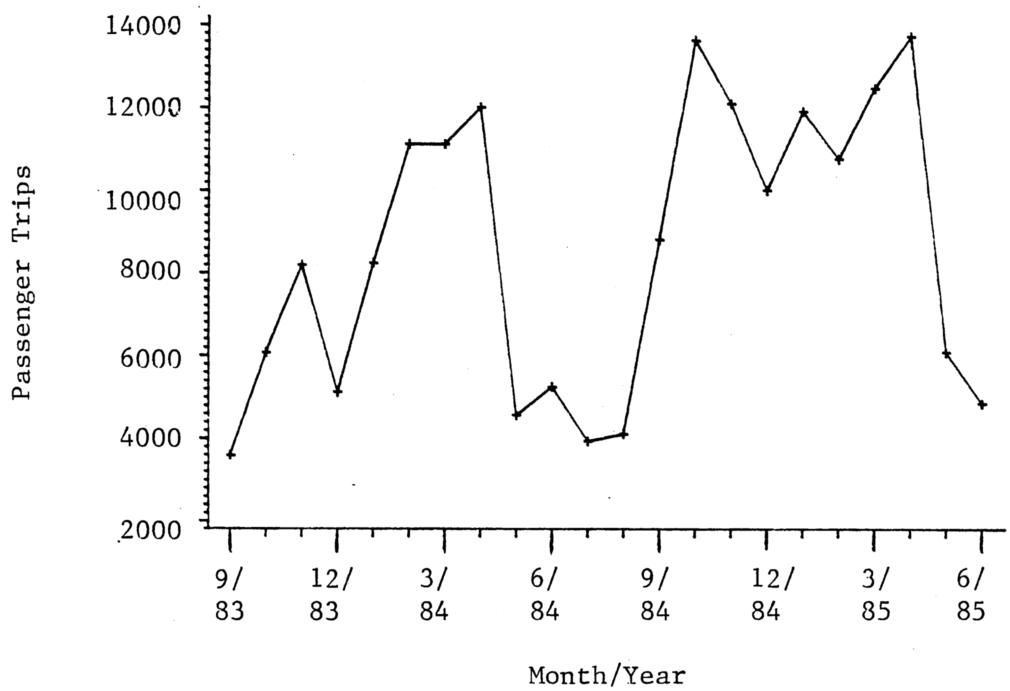


Figure 7. Passenger Trips Per Month

reductions in underutilized services may be appropriate for those months. All these actions would help stabilize operating costs per passenger trip.

CHAPTER V

RURAL TRANSIT PLANNING

Decision-Oriented Planning Approach

Problem solving techniques have been presented in a variety of ways. Usually they include the following elements: need identification, goal setting, choice of alternative, and monitoring to determine if goals are met. Planning for rural transit can be viewed in a similar framework, incorporating the tools which have been reviewed.

Need identification is the first step to effective transit planning. The need for public transit could be identified with particular population segments, such as the elderly or handicapped. Alternatively, the need may be associated with a particular route, such as a commuter route to an industrial plant or a rural route which brings passengers into the county seat. Involvement of leaders from many segments of the community can enhance the need identification process. A variety of perspectives helps planners avoid focusing on preconceived ideas.

Goal development and alternative definition follows. The goals may relate to total ridership, ridership of a segment of the population, percent of ridership capacity filled, costs of service provision, revenues collected, or many other areas. Next, various alternatives must be outlined. This involves defining the service area and the type and quantity of transit services which will be provided. It is important to identify factors which will affect various alternatives, such as community characteristics and resource limitations. Characteristics of the community will affect ridership, thus highlighting the need for ridership estimations. Resource limitations will define the financial feasibility of options. Accurate budget estimates will assist in delineating this restriction.

Finally, a procedure for monitoring must be determined before implementation of an alternative. This will allow for evaluation of progress toward achievement of goals. Once the alternative has been initiated, this feedback should be continual, and allowances made for changing needs and goals.

Considerations for Translating Goals into an Operational Plan

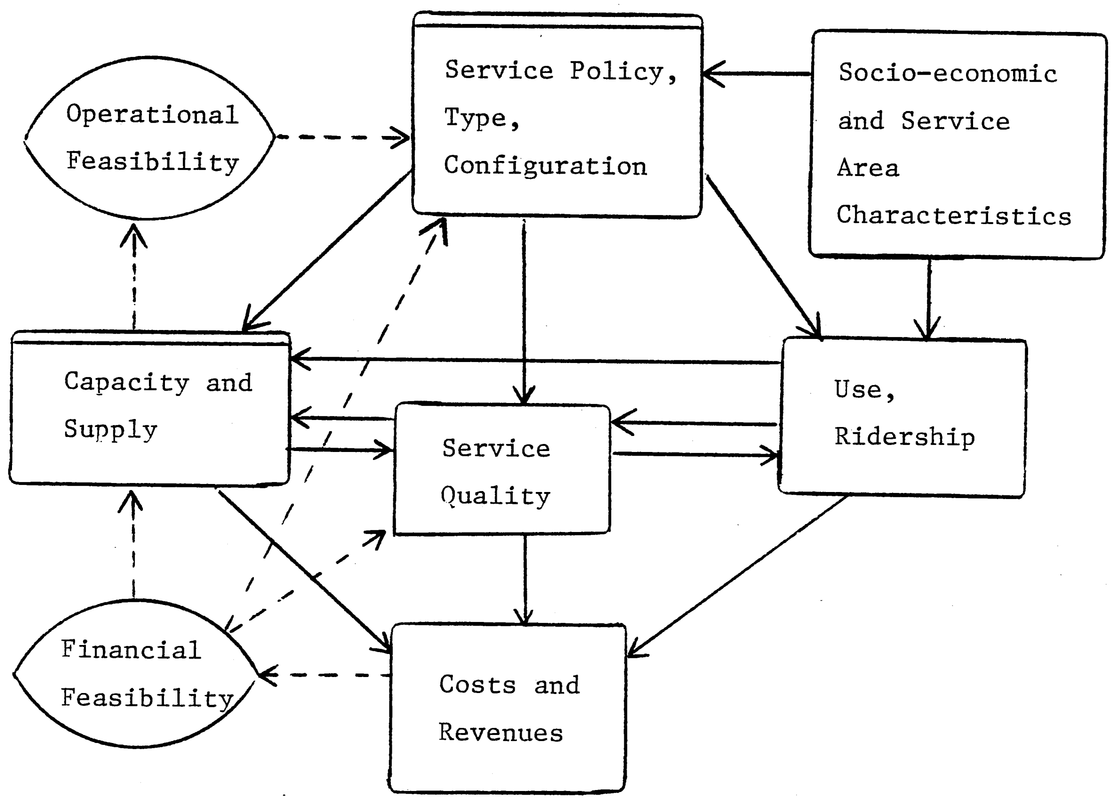
When developing an operational plan, opportunities for coordination of services should be considered. Many agencies, churches, and clubs may own vehicles and already provide transportation in the community. Some of these services may be very specialized and not within the scope of public transit, while others may duplicate proposed routes. Overlapping of routes should be avoided.

Coordination, for all of its benefits, has costs as well. Organizations that own vehicles may not be willing to give up private ownership and the freedom which it allows. There may be a perception that they will lose all control of services provided. In Oklahoma, many human service organizations have successfully pooled their vehicles into Section 18 programs. To insure adequate provision of services to their clientele, contracts have been drawn up to dictate that nutrition, Headstart, or other routes will be served by the public transit system. In effect, it allows many organizations to get out of the transit business, and devote energies to other service offerings.

Community involvement is another key element of successful rural public transit planning. Support for any community project is fostered by a feeling of ownership in that project. That feeling evolves through active participation. The involvement of some community groups, such as the Chamber of Commerce or business associations, can be encouraged by demonstrating the benefits which can be received from public transit. Other groups may perceive transit as a cause that supports their goals, and become involved by volunteering services or donating fares.

The Process of Transit Planning

Planning for transit is a continual process. The interactions between system characteristics, community characteristics, and financial and operational limitations are not unidirectional. Rather, they create a web of relationships, as depicted in Figure 8. Travel markets, service configurations, operating policies, vehicle inventory, and staff all affect the element of design. Performance is affected by service quality, use, supply, and costs. These factors do not exist in isolation. As the solid arrows indicate, there are numerous basic, functional relationships. In addition,



Source: Adapted from J.H. Batchelder, K.W. Forstall and J.A. Wensley, <u>Estimating Patronage for Community Transit Services</u> (1984).

Figure 8. Interactions in the Process of Transit Planning

operational and financial feasibility become considerations which act on the process. It should be noted that a transit system's actions are limited to two factors: capacity and supply, and service policy and configuration.

To prepare to act in these areas, the tools discussed in this research are essential. Prediction of ridership will help anticipate supply needs, as well as costs and revenues. Routing assists in proper service configuration. Budgeting allows for assessing the impact of financial feasibility, which in turn reflects on supply and service definition. Performance monitoring can evaluate the interactions with respect to the transit system's goals. The process of transit planning and management must assess all these factors, and their impact on each other. It should be continual, flexible enough to allow for adjustments as needed, and responsive to the system's goals over time.

CHAPTER VI

SUMMARY, CONCLUSIONS, AND FUTURE RESEARCH DIRECTIONS

Summary and Conclusions

People in rural areas have had to rely heavily on private vehicles for transportation. To a lesser extent, human service organizations have provided transit services to elderly, handicapped, and low income persons. Transportation is seen as a primary need for these target populations, since lack of mobility may prevent them from receiving other necessary services.

Since the inception of the Section 18 Program for Areas Other than Urbanized, rural public transit has experienced a rapid expansion. Tools for the planning and evaluation of public transit have been developed for urban areas. But these tools do not necessarily apply to rural transit because of its distinct characteristics. Rural public transit differs from its urban counterpart in the market served, service configurations, operating policies, and vehicles used. Therefore, the need for planning tools which are specifically designed for rural public transit has evolved.

Several of these tools have been reviewed. Estimates of ridership were made on a county-wide basis, as well as on a route and sector basis for fixed route and demand responsive services respectively. Regression analysis was used to develop these estimates. Socioeconomic variables, transit service characteristics, and availability of other transit were examined to determine their effect on ridership. Ridership estimates can be used to project revenues and costs, and to determine market area, type of service to be offered, and route configuration.

When a specific transit demand has been identified, such as children needing to be bussed to school or elderly persons needing transportation to a nutrition program, route development is necessary. An algorithm which generated a shortest path matrix was used in order to reduce data needs for the ROUTE program. Thus, the shortest routes for a situation could be developed given vehicle capacity, ridership information, and distances between adjacent nodes.

Budgeting is necessary to determine feasibility of a transit project. Guidelines based on capital equipment bids and operating budgets of eight rural public transit systems in Oklahoma were outlined. In addition, performance monitoring guidelines were presented. These can be used to provide an evaluation feedback loop, which is vital in the planning process. The budgeting and performance guidelines may be used by either new or existing systems.

Future Research Directions

Further research is needed to verify and better define the ridership estimation models. With several new systems coming into operation in Oklahoma this year, additional data can be collected and added to the data base. In addition, more data for existing systems can be compiled. This will allow for extended analysis.

An important area to examine in the micro models is seasonality of ridership. Because the data did not accurately report route and sector data for an entire year, this was not tested. However, as indicated in a macro equation, the season of the year did have an effect on ridership.

Another variable which should be reexamined is FARE. There was little variation in the fares reported in this data set, and as a result, the variable never appeared significant. In the future, fares may have to be adjusted to cover a larger proportion of operating costs. Demand theory would suggest that an increase in the price of transit will decrease ridership.

If the data were available, several new variables could be tested. For example, the miles run by a competing transit service may be more revealing than the variables indicating the number or presence of a competing vehicle, i.e. the variables OTHBUS and OTH. A variable which would proxy management might also be critical to model performance.

The addition of another year of data to this data base may allow for alternative specifications of the models as well. For instance, the demand responsive model might perform better if it were developed for small, medium, and large cities separately. Census breakdowns for rural and urban could be used to delineate these categories.

Another approach to predicting ridership could be termed a "life cycle" approach. Currently, observations for months early in one transit system's operation are combined with later months in another, more established operation. With more data, tests for autocorrelation could be performed and if the effects of patronage building could be delineated over several years, ridership models might be developed separately for young versus established systems.

The potential for changes in variable definition and model structure is enormous. Annual updating should be performed in an effort to improve these models. The estimation of public transit ridership is a critical first step in the planning process.

The most critical research direction to take in the areas of budgeting and performance monitoring is to continue to build a data base for rural public transit systems. By standardizing cost and trip statistic reporting procedures, comparable data on budget line items and performance measures can be developed. This will allow for more accurate budget projections for use in the planning process. In addition, increased information on performance measures would make peer groupings and peer comparisons more legitimate. More critical evaluation of systems could then occur, and subsequent increases in efficiency and effectiveness could be expected.

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APPENDIX

TABLE XXXIII

INPUT DATA FOR SHORTEST PATH APPLICATION

```
LIBRARY: TESTPATH
TYPE:    DATA

----+----1----+----
```

240	1	2
350	1	4
560	1	5
260	1	9
300	1	11
320	1	14
290	1	15
290	1	16
75	2	3
300	2	9
340	2	11
305	2	15
150	2	16
530	2	29
490	2	30
135	3	4
325	3	5
340	3	6
120	3	8
485	3	29
445	3	30
290	4	5
305	4	6
85	4	8
95	5	6
275	5	8
275	5	18
260	5	19
385	5	28
70	6	7
290	6	8
290	6	18
275	6	19
595	6	22
585	6	23
985	6	24
400	6	28
205	7	20
275	7	21
575	7	22
565	7	23
965	7	24
480	8	15
185	8	17
435	8	30
60	9	10
60	9	11
250	9	15
250	9	16
40	11	12
290	11	16
50	12	13
60	13	14
50	14	15
210	14	16
175	15	16
335	15	17
485	15	29
445	15	30
330	16	17
480	16	29
440	16	30
145	17	18
235	17	28
290	17	30
55	18	19
180	18	28
50	19	20
165	19	28
130	20	21
350	21	22
85	21	27
90	22	23
690	22	24
400	22	26
680	23	24
100	24	25
790	24	26
1310	24	30
810	25	26
1330	25	30
165	26	27
395	26	28
260	27	28
325	28	30
100	29	30

TABLE XXXIV

SHORTEST PATH PROGRAM

MEMBER: DEBLANK

```
DEBLANK: PROC(LINE)                RETURNS(CHAR(100) VAR) REORDER;
/*********************************************************************
/*  Procedure: The DEBLANK function is used to remove leading and    *
/*             trailing blanks from a varing character string.       *
/*                                                                   *
/*  Programmers : James Alexander & Shari McClure                    *
/*                Nov. 1, 1984                                       *
/*                Department of Ag. Econ.                            *
/*                Oklahoma State University                          *
/*                                                                   *
/*  Inputs  : LINE           Character varing, contains the string   *
/*                           to be "deblanked".                      *
/*                                                                   *
/*  Outputs : OUT_LINE       Character 100 varing, contains the      *
/*                           "deblanked" string to be returned.      *
/*                                                                   *
/*  Internal Variables :     NONE                                    *
/*                                                                   *
/*  Functions Used :                                                 *
/*            SUBSTR         Builtin character handeling function.   *
/*            LENGTH         Builtin character handeling funciion.   *
/*                                                                   *
/*********************************************************************

  DCL LINE                         CHAR(*) VAR,
      OUT_LINE                     CHAR(100) VAR;

  OUT_LINE = LINE;

  IF OUT_LINE ¬= '' THEN
    DO WHILE (SUBSTR(OUT_LINE,1,1) = ' ');
    OUT_LINE = SUBSTR(OUT_LINE,2);
  END;

  IF OUT_LINE ¬= '' THEN
    DO WHILE(SUBSTR(OUT_LINE,LENGTH(OUT_LINE)) = ' ');
    OUT_LINE = SUBSTR(OUT_LINE,1,(LENGTH(OUT_LINE)-1));
  END;

  RETURN(OUT_LINE);

END DEBLANK;
```

TABLE XXXIV (Continued)

MEMBER: DUMP

```
DUMP: PROC REORDER;

  DCL PTR                              POINTER,
      I                                FIXED BIN,
      COUNT                            FIXED BIN;

  DO I = 1 TO NUMBER_VERTICES;
    PUT FILE(SYSPRINT) EDIT(I) (SKIP(2),F(4));
    PTR = ADJ_LIST(I);
    COUNT = 8;

    DO WHILE(PTR ¬= NULL);
      IF COUNT = 8 THEN DO ;
        COUNT = 0;
        PUT FILE(SYSPRINT) EDIT
          (PTR->VERTEX,PTR->WEIGHT,' --> ')
          (COL(10),F(3),X(1),F(4),A);
      END;
      ELSE PUT FILE(SYSPRINT) EDIT
        (PTR->VERTEX,PTR->WEIGHT,' --> ')
        (F(3),X(1),F(4),A);
      COUNT = COUNT + 1;
      PTR = PTR->LINK;
    END;

  END;
END DUMP;
```

MEMBER: GO

```
//BETSY     JOB (?,ALE-XA-NDER),'MEM:PLIX',CLASS=F,TIME=(,05),
//          MSGCLASS=E,MSGLEVEL=(1,0),NOTIFY=*
/*PASSWORD ?
/*ROUTE PRINT LOCAL
/*JOBPARM FORMS=9001,ROOM=N
//GOGOGO    EXEC PGM=PATH,PARM='/30'
//STEPLIB   DD DSN=U12695B.LIBRARY.LOAD,DISP=SHR
//PATHS     DD DSN=U14992A.TESTPATH.DATA,DISP=SHR
//MATRIX    DD DSN=U14992A.DMATRIX.DATA,DISP=OLD
//RESULTS   DD SYSOUT=A
//SYSPRINT DD SYSOUT=A
//
```

TABLE XXXIV (Continued)

MEMBER: INSERT

```
INSERT: PROC(VTX1,VTX2,WGT) REORDER;

  DCL VTX1                              FIXED BIN,
      VTX2                              FIXED BIN,
      WGT                               FIXED BIN(31),

      PTR                               POINTER,
      LAST_PTR                          POINTER,
      NEXT_PTR                          POINTER;

  ALLOCATE NODE SET(PTR);
  PTR->VERTEX = VTX2;
  PTR->WEIGHT = WGT;

  LAST_PTR = NULL;
  NEXT_PTR = ADJ_LIST(VTX1);

  DO WHILE(NEXT_PTR ¬= NULL);
    IF NEXT_PTR->WEIGHT > PTR->WEIGHT THEN LEAVE;
    LAST_PTR = NEXT_PTR;
    NEXT_PTR = NEXT_PTR->LINK;
  END;

  IF LAST_PTR = NULL THEN ADJ_LIST(VTX1) = PTR;
  ELSE LAST_PTR->LINK = PTR;

  PTR->LINK = NEXT_PTR;

END INSERT;
```

TABLE XXXIV (Continued)

MEMBER: PATH

```
PATH: PROC(PARAMETERS) OPTIONS(MAIN) REORDER;

  DCL PARAMETERS                      CHAR(100) VAR,

      1 NODE                          BASED,
        2 VERTEX                      FIXED BIN,
        2 WEIGHT                      FIXED BIN(31),
        2 LINK                        POINTER,

      PTR                             POINTER,

      NUMBER_VERTICES                 FIXED BIN INIT(0),
      START                           FIXED BIN,
      FINISH                          FIXED BIN,
      COUNT                           FIXED BIN(31) INIT(0),
      COUNT1                          FIXED BIN(31) INIT(0),

      YES                             BIT(1) INIT('1'B),
      NO                              BIT(1) INIT('0'B),

      SYSIN                           FILE,
      SYSPRINT                        FILE PRINT,
      RESULTS                         FILE PRINT,
      MATRIX                          FILE STREAM
                                      ENV(FB RECSIZE(70) BLKSIZE(7000)),

      NULL                            BUILTIN,
      INDEX                           BUILTIN,
      SUBSTR                          BUILTIN,
      LENGTH                          BUILTIN;

   ON ENDPAGE(RESULTS) BEGIN;
     PUT FILE(RESULTS) EDIT
       ('FROM    TO      DISTANCE     ROUTE')
       (PAGE,COL(2),A);
     PUT FILE(RESULTS) SKIP(2);
   END;

   OPEN FILE(MATRIX) OUTPUT LINESIZE(70);

   NUMBER_VERTICES = PEEL(PARAMETERS);


  BEGIN REORDER;

   DCL 1 GEN_IN(0:NUMBER_VERTICES),
         2 V2LINK                     FIXED BIN
                                      INIT((NUMBER_VERTICES) (0),0),
         2 D                          FIXED BIN(31)
                                      INIT((NUMBER_VERTICES) (0),0),
         2 PARENT                     FIXED BIN
                                      INIT((NUMBER_VERTICES) (0),0),
         2 VSET                       FIXED BIN
```

TABLE XXXIV (Continued)

MEMBER: PATH

```
       2 ADJ_LIST                         INIT((NUMBER_VERTICES) (0),0),
                                          POINTER
                                         INIT((NUMBER_VERTICES) (NULL),NULL);

   CALL READ_PATHS;
   CALL DUMP;

   SIGNAL ENDPAGE(RESULTS);

   DO START = 1 TO (NUMBER_VERTICES-1);
     DO FINISH = (START+1) TO NUMBER_VERTICES;
     IF SHORTEST_PATH(START,FINISH) THEN CALL PUT_RESULTS(START,FINISH);
     ELSE PUT FILE(RESULTS) EDIT('NO PATH FOR : ',START,FINISH)
                                 (SKIP,A,F(4),F(4));
     END;
   END;

   %INCLUDE READPATH;
   %INCLUDE SORTPATH;
   %INCLUDE RESULTS;
   %INCLUDE DUMP;

 END;

 %INCLUDE PEEL;

 END PATH;
```

MEMBER: PEEL

```
 PEEL: PROC(STRING)                 RETURNS(CHAR(100) VAR) REORDER;

   DCL STRING                       CHAR(*) VAR,
       SKIN                         CHAR(100) VAR;

   STRING = DEBLANK(STRING);

   IF INDEX(STRING,' ') = 0 THEN DO;
     SKIN = STRING;
     STRING = '';
     RETURN(SKIN);
   END;

   SKIN = SUBSTR(STRING,1,INDEX(STRING,' ')-1);
   STRING = SUBSTR(STRING,INDEX(STRING,' ')+1);
   STRING = DEBLANK(STRING);

   RETURN(SKIN);

 END PEEL;

 %INCLUDE DEBLANK;
```

TABLE XXXIV (Continued)

MEMBER: PLIX

```
//SHARI      JOB (?,ALE-XA-NDER),'MEM:PLIX',CLASS=F,TIME=(,5),
//           MSGCLASS=X,MSGLEVEL=(1,0),NOTIFY=*
/*PASSWORD OXID,FAST
/*ROUTE PRINT RMT5
/*JOBPARM FORMS=AGEC,ROOM=C404
//COMPILE    EXEC PLIXCL,
//     PARM='OBJECT,NODECK,SOURCE,OPT(TIME),INCLUDE,GONUMBER,FLAG(I)'
//PLI.SYSLIB     DD DSN=U12695B.PATH.PLI,DISP=SHR
//PLI.SYSIN      DD DSN=U12695B.PATH.PLI(PATH),DISP=SHR
//LKED.SYSLMOD DD DSN=U12695B.LIBRARY.LOAD(PATH),DISP=OLD
//
```

MEMBER: READPATH

```
READ_PATHS: PROC REORDER;

  DCL VTX(2)                         FIXED BIN,
      WGT                            FIXED BIN(31),
      I                              FIXED BIN,

      EOF                            BIT(1) INIT('0'B),

      PATHS                          FILE STREAM INPUT;

  ON ENDFILE(PATHS) EOF = YES;

  ON UNDEFINEDFILE(PATHS) BEGIN REORDER;
    PUT FILE(SYSPRINT) EDIT
      ('***** ERROR *****',
       'ERROR OCCURED IN OPENING FILE "PATHS",',
       ' CHECK YOU JCL STATEMENTS FOR THE CORRECT ALLOCATION.')
      (SKIP(3),A,SKIP,A,A);
    STOP;
  END;

  OPEN FILE(PATHS);

  GET FILE(PATHS) EDIT(WGT,VTX(1),VTX(2))
    (COL(1),F(4),F(4),F(4));

  DO WHILE(¬EOF);
    CALL INSERT(VTX(1),VTX(2),WGT);
    CALL INSERT(VTX(2),VTX(1),WGT);
    GET FILE(PATHS) EDIT(WGT,VTX(1),VTX(2))
      (COL(1),F(4),F(4),F(4));
  END;

  CLOSE FILE(PATHS);

END READ_PATHS;

%INCLUDE INSERT;
```

TABLE XXXIV (Continued)

MEMBER: RESULTS

```
PUT_RESULTS: PROC(STR,FIN) REORDER;

  DCL (START,FINISH)                FIXED BIN,
      (STR,FIN)                     FIXED BIN;

  START = STR;
  FINISH = FIN;

  PUT FILE(MATRIX) EDIT(D(START),START,FINISH) (F(6),2(F(4)));

  PUT FILE(RESULTS) EDIT
    (START,FINISH,D(START),' ')
    (COL(3),F(3),COL(9),F(3),COL(17),F(5),A);

  DO WHILE(START ¬= FINISH);
    PUT FILE(RESULTS) EDIT
      (START,' --> ')
      (F(3),A);
    START = PARENT(START);
  END;
  PUT FILE(RESULTS) EDIT(FINISH) (F(3));

END PUT_RESULTS;
```

TABLE XXXIV (Continued)

MEMBER: SORTPATH

```
SHORTEST_PATH: PROC(START,FINISH) RETURNS(BIT(1)) REORDER;

  DCL FINISH                            FIXED BIN,
      START                             FIXED BIN,
      (I,X,Y,Z)                         FIXED BIN;

  DO I = 1 TO NUMBER_VERTICES;
    VSET(I) = 3;
  END;

  VSET(FINISH) = 1;
  X = FINISH;
  D(FINISH) = 0;
  V2LINK(0) = -1;

  DO WHILE(X ¬= START);
    PTR = ADJ_LIST(X);

    DO WHILE(PTR ¬= NULL);
      Y = PTR->VERTEX;
      IF VSET(Y) = 2 & ((D(X) + PTR->WEIGHT) < D(Y)) THEN DO;
        PARENT(Y) = X;
        D(Y) = D(X) + PTR->WEIGHT;
      END;

      IF VSET(Y) = 3 THEN DO;
        VSET(Y) = 2;
        V2LINK(Y) = V2LINK(0);
        V2LINK(0) = Y;
        PARENT(Y) = X;
        D(Y) = D(X) + PTR->WEIGHT;
      END;
      PTR = PTR->LINK;
    END;

    IF V2LINK(0) = -1 THEN RETURN(NO);

    Y = 0;
    Z = 0;
    DO WHILE(V2LINK(Z) ¬= -1);
      IF D(V2LINK(Z)) < D(V2LINK(Y)) THEN Y = Z;
      Z = V2LINK(Z);
    END;
    Z = Y; Y = V2LINK(Y);
    V2LINK(Z) = V2LINK(V2LINK(Z));

    VSET(Y) = 1;
    X = Y;
  END;

  RETURN(YES);

END SHORTEST_PATH;
```

TABLE XXXV

MATRIX OUTPUT FROM SHORTEST PATH PROGRAM

DMATRIX
DATA

240	1	2	315	1	3	350	1	4	560	1	5	655	1	6
725	1	7	435	1	8	260	1	9	320	1	10	300	1	11
340	1	12	380	1	13	320	1	14	290	1	15	290	1	16
620	1	17	765	1	18	820	1	19	870	1	20	1000	1	21
1250	1	22	1240	1	23	1640	1	24	1740	1	25	1250	1	26
1085	1	27	855	1	28	770	1	29	730	1	30	75	2	3
210	2	4	400	2	5	415	2	6	485	2	7	195	2	8
300	2	9	360	2	10	340	2	11	380	2	12	415	2	13
355	2	14	305	2	15	150	2	16	380	2	17	525	2	18
580	2	19	630	2	20	760	2	21	1010	2	22	1000	2	23
1400	2	24	1500	2	25	1010	2	26	845	2	27	615	2	28
530	2	29	490	2	30	135	3	4	325	3	5	340	3	6
410	3	7	120	3	8	375	3	9	435	3	10	415	3	11
455	3	12	490	3	13	430	3	14	380	3	15	225	3	16
305	3	17	450	3	18	505	3	19	555	3	20	685	3	21
935	3	22	925	3	23	1325	3	24	1425	3	25	935	3	26
770	3	27	540	3	28	485	3	29	445	3	30	290	4	5
305	4	6	375	4	7	85	4	8	510	4	9	570	4	10
550	4	11	590	4	12	625	4	13	565	4	14	515	4	15
360	4	16	270	4	17	415	4	18	470	4	19	520	4	20
650	4	21	900	4	22	890	4	23	1290	4	24	1390	4	25
900	4	26	735	4	27	505	4	28	620	4	29	520	4	30
95	5	6	165	5	7	275	5	8	700	5	9	760	5	10
740	5	11	780	5	12	815	5	13	755	5	14	705	5	15
550	5	16	420	5	17	275	5	18	260	5	19	310	5	20
440	5	21	690	5	22	680	5	23	1080	5	24	1180	5	25
690	5	26	525	5	27	385	5	28	810	5	29	710	5	30
70	6	7	290	6	8	715	6	9	775	6	10	755	6	11
795	6	12	830	6	13	770	6	14	720	6	15	565	6	16
435	6	17	290	6	18	275	6	19	275	6	20	345	6	21
595	6	22	585	6	23	985	6	24	1085	6	25	595	6	26
430	6	27	400	6	28	825	6	29	725	6	30	360	7	8
785	7	9	845	7	10	825	7	11	865	7	12	900	7	13
840	7	14	790	7	15	635	7	16	455	7	17	310	7	18
255	7	19	205	7	20	275	7	21	575	7	22	565	7	23
965	7	24	1065	7	25	525	7	26	360	7	27	420	7	28
845	7	29	745	7	30	495	8	9	555	8	10	535	8	11
575	8	12	590	8	13	530	8	14	480	8	15	345	8	16
185	8	17	330	8	18	385	8	19	435	8	20	565	8	21
885	8	22	875	8	23	1275	8	24	1375	8	25	815	8	26
650	8	27	420	8	28	535	8	29	435	8	30	60	9	10
60	9	11	100	9	12	150	9	13	210	9	14	250	9	15
250	9	16	580	9	17	725	9	18	780	9	19	830	9	20
960	9	21	1310	9	22	1300	9	23	1700	9	24	1800	9	25
1210	9	26	1045	9	27	815	9	28	730	9	29	690	9	30
120	10	11	160	10	12	210	10	13	270	10	14	310	10	15
310	10	16	640	10	17	785	10	18	840	10	19	890	10	20
1020	10	21	1370	10	22	1360	10	23	1760	10	24	1860	10	25
1270	10	26	1105	10	27	875	10	28	790	10	29	750	10	30
40	11	12	90	11	13	150	11	14	200	11	15	290	11	16
535	11	17	680	11	18	735	11	19	785	11	20	915	11	21
1265	11	22	1340	11	23	1740	11	24	1840	11	25	1165	11	26
1000	11	27	770	11	28	685	11	29	645	11	30	50	12	13
110	12	14	160	12	15	320	12	16	495	12	17	640	12	18

TABLE XXXV (Continued)

DMATRIX
DATA

695	12	19	745	12	20	875	12	21	1225	12	22	1315	12	23
1780	12	24	1880	12	25	1125	12	26	960	12	27	730	12	28
645	12	29	605	12	30	60	13	14	110	13	15	270	13	16
445	13	17	590	13	18	645	13	19	695	13	20	825	13	21
1175	13	22	1265	13	23	1815	13	24	1885	13	25	1075	13	26
910	13	27	680	13	28	595	13	29	555	13	30	50	14	15
210	14	16	385	14	17	530	14	18	585	14	19	635	14	20
765	14	21	1115	14	22	1205	14	23	1755	14	24	1825	14	25
1015	14	26	850	14	27	620	14	28	535	14	29	495	14	30
175	15	16	335	15	17	480	15	18	535	15	19	585	15	20
715	15	21	1065	15	22	1155	15	23	1705	15	24	1775	15	25
965	15	26	800	15	27	570	15	28	485	15	29	445	15	30
330	16	17	475	16	18	530	16	19	580	16	20	710	16	21
1060	16	22	1150	16	23	1550	16	24	1650	16	25	960	16	26
795	16	27	565	16	28	480	16	29	440	16	30	145	17	18
200	17	19	250	17	20	380	17	21	730	17	22	820	17	23
1420	17	24	1440	17	25	630	17	26	465	17	27	235	17	28
390	17	29	290	17	30	55	18	19	105	18	20	235	18	21
585	18	22	675	18	23	1275	18	24	1295	18	25	485	18	26
320	18	27	180	18	28	535	18	29	435	18	30	50	19	20
180	19	21	530	19	22	620	19	23	1220	19	24	1240	19	25
430	19	26	265	19	27	165	19	28	590	19	29	490	19	30
130	20	21	480	20	22	570	20	23	1170	20	24	1190	20	25
380	20	26	215	20	27	215	20	28	640	20	29	540	20	30
350	21	22	440	21	23	1040	21	24	1060	21	25	250	21	26
85	21	27	345	21	28	770	21	29	670	21	30	90	22	23
690	22	24	790	22	25	400	22	26	435	22	27	695	22	28
1120	22	29	1020	22	30	680	23	24	780	23	25	490	23	26
525	23	27	785	23	28	1210	23	29	1110	23	30	100	24	25
790	24	26	955	24	27	1185	24	28	1410	24	29	1310	24	30
810	25	26	975	25	27	1205	25	28	1430	25	29	1330	25	30
165	26	27	395	26	28	820	26	29	720	26	30	260	27	28
685	27	29	585	27	30	425	28	29	325	28	30	100	29	30

VITA 2

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